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JOURNAL

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Perspective

USAARL – Preserving the Combat Effectiveness and Survivability of the Soldier Warrior

Brigadier General Daniel F. Perugini

The U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, AL, is one of six laboratories within the U.S. Army Medical Research and Materiel Command (USAMRMC). The organization was established in 1962 to provide direct aviation medical research support to Army aviation and airborne activities. Its primary mission remains the medical research support of aviation. Since then, USAMRMC responsibilities have expanded to include designation as the lead medical laboratory for vision and acoustics research, and conducting health hazard assessments on air and ground vehicles and weapons systems. The laboratory is configured with two research divisions: Aircrew Health and Performance and Aircrew Protection. It works closely with other USAMRMC laboratories and conducts collaborative research with Department of Defense and other federal agencies concerning aviation medical research and the development of issues of common concern.

A wide variety of research and development projects are currently being conducted at USAARL to meet the diverse issues concerning health hazards within the Army aviation community. The main objectives of these projects include health hazard assessments of aviation and associated weapons systems, the conduct of airborne operations, the role of stress and fatigue, aeromedical evacuation, and the development of aircrew selection. Current aviation research studies include head-supported mass effects on Soldiers; effects of repeated jolting and shaking on the human body; corneal topography and optical aberration modeling; spatial disorientation; fatigue and crew coordination; and circadian rhythm effects on individual and crew performance. Integration of these results and those of other studies have had a profound impact on both the day-to-day and wartime conduct of aviation missions.

I think you will find this issue of the AMEDD Journal to be both interesting and informative. It offers a look at the unique, complex, and rewarding world of specialized military medical research.

- One task assigned to the USAARL is to investigate the reasons leading to U.S. Army aircraft accidents and to develop improved safety measures and training regimens to decrease the possibility of future mishaps. *The Role of Helmet-Mounted Displays in AH-64 Apache Accidents* explores the possible involvement of the Integrated Helmet and Display and the Pilot's Night Vision System as causative factors in AH-64 helicopter accidents. *Human Factors in U.S. Army Unmanned Aerial Vehicle Accidents* compares the Human Factors Analysis and Classification System with the methodology defined in Department of the Army Pamphlet 385-40 for evaluating the human role in accidents involving unmanned aerial vehicles. A third article, *Human Error and Individual Failures in U.S. Army Aviation Accidents*, explores the different types of human error that have been implicated in close to one-half to three-quarters of Army aircraft accidents.

- While helmets provide important protection, they also increase the weight supported by the neck, thus potentially increasing the risk of neck injury. The safety of new helmet-mounted devices for both aircraft crewmembers and parachutists is of special concern for potentially increasing injuries. *Parachutist Neck Injury Risk Associated with Head-Borne Mass* discusses a study evaluating the Individual Combat Identification System by means of a manikin instrumented to measure neck loads in a variety of test scenarios.

- Spatial hearing allows humans to locate sound sources, detect movement, and focus on a specific source; this ability has multiple applications in the conduct of military operations. *Spatial Hearing, Hearing Impairments, and Hearing Protection* is an analysis of various audio systems to measure individual "head-related transfer functions" and generate 3-dimensional sound. The author supports his findings with a series of detailed, informative graphics.

- Is it possible to correct higher order aberrations of the eye to correct a pilot's vision? *Focus on Supernormal Vision* discusses the impact of laser refractive surgery on vision correction and the newer technologies that have been developed to measure higher-order abnormalities.

- The study of motion and vibrations in humans is called actigraphy and was originally developed in the 1920s as a means of sleep measurement based on body movements. *Warfighter Biovibrations* presents an in-depth look at the current actigraphy technology and its application in the Future Force Warrior Program.

- Other articles in this issue discuss pertinent topics relating to current military operations in Iraq and Afghanistan. *Enhanced Blast Weapons and Forward Medical Treatment* discusses the effect of enhanced blast weapons and the primary concerns facing medical personnel in dealing with injuries related to these weapons.

- One innovation in Army medicine is the application of communications technology to improve patient care. *Implementing Teledermatology in a Military Clinic* explains how a U.S. Army satellite clinic in Puerto Rico utilizes teledermatology for patients beyond the scope of care offered on-site.

- *Battlefield Medicine: A Tactical Perspective* divides casualty care into three phases: Care Under Fire, Tactical Field Care, and Combat Casualty Evacuation Care. The authors discuss the challenges presented in providing lifesaving medical care, especially for the MOS 91W Combat Medic, in these significantly different scenarios.

From the Commander, U.S. Army Aeromedical Research Laboratory

Colonel James S. McGhee

(Text of the presentation by COL McGhee at the dedication of the Neel Aeromedical Science Center, Fort Rucker, AL, on 2 Apr 04.)

Distinguished Guests and friends of USAARL, thank you for being with us for this dedication, and for helping us celebrate the memory of a great man. We are also celebrating the dedicated professionals who serve in the laboratory today, and, who have served here in the past. Our successes reflect the finest values of our country – daring, discipline, ingenuity, and unity in the pursuit of great goals.

We have focused a lot of attention on history thus far in the program, but this organization is not about past accomplishments. The true legacy that this laboratory's founders left for us is one of analytical, forward thinking vision. It was the ability to develop a vision that led to the solutions of their day. Today, as then, vision, tempered with a sharp, operational focus, will prove to be the vital capability needed to look down the road ahead and solve the warfighter challenges of our day with innovation and ingenuity, and to anticipate future challenges.

The risk takers and visionaries of this laboratory expanded the body of human knowledge, revolutionized our understanding of the Soldier in the flight environment, and produced technological advances that benefited the entire force; they continue to do so today.

Inspired by all that has come before, and guided by clear objectives, today we renew our dedication to charting a new course. We are an integral part of the Medical Research and Material Command's family of six laboratories. We fully subscribe to collaborating with our sister laboratories and partnering with other Department of Defense, academic, and industrial agencies in our goal of evaluating and developing essential technologies vital to the warfighter of today and the future. The MRMC vision is to "deliver the best medical solutions, for today and tomorrow, to enhance, protect, and treat the warfighter on point for the Nation."

Our research focus on the enhancement of acoustic, visual, and cognitive performance aspects of the Future Force Air Warrior have yielded benefits for Army aircrews as well as Land Warrior forces, mounted and dismounted.

As technological advances formerly found only in advanced aircraft migrate from those aircraft to ground force

equipment, USAARL leads the way in integrating knowledge gained through aviation-oriented research into the Army's new Joint and Expeditionary mindset.

Our proud roots are in Army Aviation, and our future, like aviation's, lies with the Total Force.

The USAARL is a key player in the Global Health Force Protection team. Our integrated approach to visual, cognitive, and hearing performance and protection is unrivaled in the biomedical research community. The USAARL's facilities and scientific experience and expertise in human protective equipment are unmatched. Our scientific methods and research products are of the highest quality as measured by scientific peer review and customer assessment. We have maintained a reputation in the joint community as an honest broker in the evaluation of MEDEVAC equipment. Our scientists place the safety, health, and well-being of the Soldier/aviator first as they work to accomplish the daunting task of minimizing health hazards and improving effectiveness.

Yet, for all these successes, much remains for us to explore and to learn. We continue to make advances in the field of 3-dimensional acoustic arrays, super-normal vision and aviation pharmacology – to name just a few. The USAARL's mission remains – through research – to preserve and enhance the health, safety, combat effectiveness, and survivability of the Soldier Warrior. Our challenge was set before us by the

United States Army Aeromedical Research Laboratory

An Army Center of Excellence in Research for Today's Warfighter

The United States Army Aeromedical Research Unit was established in October 1962. As envisioned by the late Major General Spurgeon Neel, U.S. Army (Retired), the unit's mission was to provide direct aviation medical research support to all Army aviation and airborne activities. Technical evaluation of aircraft and personnel equipment, aeromedical in-flight observations, and analyses of field problems reported by other aviation agencies were part of the unit's early research.

In 1969, it was redesignated a laboratory, and construction began on a new vivarium. A year later, the Helicopter In-flight Monitoring System, an airborne system capable of simultaneously measuring pilot and helicopter performance, was designed, built, and installed aboard the Laboratory's JUH-1H research helicopter. Researchers assessed prototype lighting systems and paint schemes for helicopter collision avoidance. A burn laboratory was constructed for studies of post-crash fire characteristics of helicopters and human survival and protection.

In 1973, USAARL researchers designed and had fabricated the Military Anti-Shock Trousers. This innovation proved to be a lifesaving tool for rescue squads answering calls involving trauma victims.

In 1974, a field research facility was completed at a Fort Rucker stage field to permit research assessing physiological and psychological aviator performance during sustained operations. A helmet evaluation facility was completed in 1975. Investigations into human effects of helicopter vibration were begun on the man-rated multi-axis ride simulator.

The USAARL's research efforts have been directed toward aviation. With a chemical threat and the introduction of new weapons systems, armored vehicles, and individual equipment, the Laboratory's research capabilities also were required to address operational problems in other military settings. In 1977, the analysis of psychophysiologic requirements and performance of combat vehicle crews began. Research on blast overpressure and impulse noise from individual and crew-served weapons contributed to acoustic safety standards for human exposure. Knowledge obtained through this research was instrumental in establishing requirements for health hazard assessment for emerging military systems.

Now, in the 21st century, USAARL is expanding its research to encompass the entire spectrum of military operations. Physicians, engineers, and safety experts work together to understand human injuries and damage to personal protective equipment from a crash. Researchers analyze design and deficiencies in flight helmets, crashworthy seating, and restraint systems; and develop criteria for future Objective Force warfighter systems that will include infantry, airborne, mechanized, and aviation.

During the 1980s, USAARL researchers became increasingly involved in field studies. They assessed hazards of military systems and operations as well as the biomedical means of enhancing Soldier selection, performance, and protection. Throughout the 1990s and into the 21st century, our scientists continue laboratory and field studies on the ground and in helicopter flight in a variety of research disciplines – vision and visual enhancement/protection, auditory injury/protection, impact injury/protection, jolt effects, crew stress/workload, and physiological life support.

Neel Aeromedical Science Center Dedicated

At a ceremony held on 2 April 2004, the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, AL, was dedicated in honor and memory of Major General Spurgeon H. Neel, a Soldier, physician, visionary, and leader. The USAARL is one of the six research laboratories of the U.S. Army Medical Research and Materiel Command (MRMC), Fort Detrick, MD. Major General Lester Martinez Lopez, Commanding General, MRMC, was host. Ms Alice Neel, as the honored guest, unveiled the bronze plaque dedicated to her late husband. The USAARL building was named the Neel Aeromedical Science Center.

Major General Neel was born and educated in Memphis, TN. He entered active duty in October 1943, following his internship at Methodist Hospital in Memphis. At the end of World War II, he was commander of a medical company in Europe. In the following 40 years of his career, MG Neel was involved in all phases of field and aviation medicine. He established a formal program for Board Certification in Aviation Medicine for Army Medical Officers and created the Army Aviation Medical Training and Research Programs.

Major General Neel was a pioneer in the development of the principles of aeromedical evacuation of battlefield casualties. His guidance and suggestions were implemented during the Korean conflict, with a resulting significant increase in the number of injured Soldiers removed from the battlefield. Based on his experience during that conflict, he developed medical evacuation policies, procedures, and organizations that are currently the foundation of aeromedical operations.

As the hostilities in Vietnam increased in the mid-1960s, COL Neel was assigned as the Chief Surgeon, U.S. Military Assistance Command and Senior Medical Advisor to General William Westmoreland. Following his promotion to Brigadier General in 1968, he became the Commanding General of the 44th Medical Brigade. Upon his return to the United States, BG Neel was nominated to become Deputy Army Surgeon General, a post he held until 1973, when he became the first Commanding General of U.S. Army Health Services Command.

Regarded as the Father of modern Army Aviation Medicine, MG Neel envisioned a research facility charged with the mission of providing direct aviation medical research support to all Army aviation and airborne activities. His goal was realized in 1962 with the creation of the U.S. Army Aeromedical Research Unit; MG General Neel's vision grew into today's U.S. Army Aeromedical Research Laboratory, a center of excellence devoted to world-class research on health hazards of Army aviation, tactical combat vehicles, selected weapons systems, and airborne operations.

The Role of Helmet-Mounted Displays in AH-64 Apache Accidents

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Introduction

The AH-64 Apache is the U.S. Army's most advanced rotary-wing attack aircraft (Figure 1). It exists in two model configurations, the AH-64A and AH-64D. The AH-64D is referred to as having a "glass cockpit." This reference is made to the modified crew station design employed in the AH-64D that replaces most of the traditional dedicated instruments with multifunction displays. The D-model also has an expanded mission capability and may present a higher workload cockpit.

The AH-64 is flown using a helmet-mounted display (HMD) known as the Integrated Helmet and Display Sighting System (IHADSS) (Figure 2). This HMD presents pilotage imagery and flight symbology. Pilotage imagery originates from a nose-mounted forward-looking infrared (FLIR) sensor known as the Pilot's Night Vision System (PNVS). Several studies have identified a number of visual problems and illusions that may be contributing factors to AH-64 accidents.[1-5]

This study analyzed AH-64 accidents over the time period 1 Oct 84 to 31 Mar 02 (fiscal years [FYs] 85 to second quarter 02). The analysis focused primarily on accidents that can be attributed to flight with the IHADSS HMD and/or PNVS/FLIR imagery in the AH-64. Accidents associated with aircraft mechanical failure (other than relating to the FLIR or IHADSS) were tabulated but not analyzed. The objective of this study was to investigate the possible role HMD and PNVS use may have played in AH-64 Apache accidents.

Background

The Army's AH-64 Apache attack helicopter uses a tandem-seating configuration. The dedicated instrument A-model was fielded in 1985. The glass cockpit D-model was introduced in 1997. The two cockpit designs are presented in Figure 3. The total flight hours for the AH-64A and AH-64D

Fig 1. The AH-64D Apache helicopter.

Fig 2. IHADSS.

Fig 3. Cockpit views of the AH-64A (left) and AH-64D (right).
(Lower photos courtesy of Boeing Aircraft Corporation)

models (as of 31 Mar 02) were 1,341,397 and 81,433, respectively.

The AH-64 achieves its night and foul-weather capabilities through the use of two nose-mounted FLIR sensors (Figure 4). One is used for pilotage and one for targeting. The targeting FLIR sensor is known as the Target Acquisition and Designation System (TADS). The pilotage FLIR is the PNVS. Both FLIR sensors operate in the 8-12 micron spectral range.

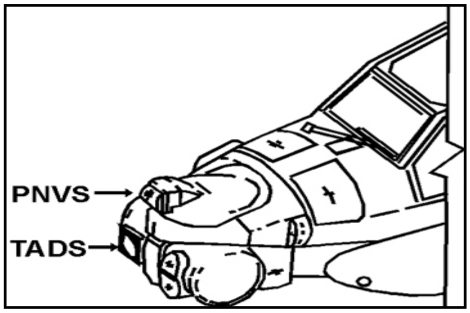

Fig 4. The PNVS and TADS nose-mounted FLIR sensors on the AH-64.

The FLIR imagery, along with aircraft status symbology, is displayed to the pilots via the AH-64s HMD, the IHADSS. The IHADSS consists of the helmet display unit (HDU) (Figure 5), which is an optical relay unit incorporating a miniature 1-inch cathode ray tube (CRT). The HDU is mounted on the right side of the IHADSS helmet. Video imagery originating from the nose-mounted FLIR sensor is presented on the face of the CRT and is optically relayed and reflected off a beam splitter (combiner) into the pilot's right eye. The presented imagery subtends a field of view (FOV) of 30 degrees vertically by 40 degrees horizontally. This imagery, presented to the right eye only, is what the pilot uses to fly and operate the AH-64 at night. The left eye is unaided, allowing the pilot to view cockpit displays and the outside world.

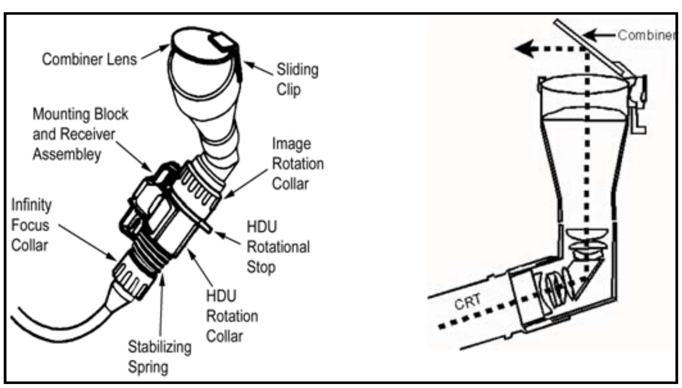

Fig 5. Two views of the IHADSS HDU.

The AH-64 with its PNVS FLIR sensor and IHADSS HMD is a very challenging aircraft to fly. The pilot is expected to control and fly this tremendously sophisticated piece of machinery from a limited FOV (30 degrees vertical x 40 degrees horizontal) picture of the outside world that is a representation of the outside scene in a completely different spectral range (8-12 microns). Piloting and operating an aircraft in a military environment using an HMD places extraordinary demands on the human visual system. It is not unreasonable to suspect that this demanding visual and processing workload may contribute to, if not cause, accidents. This is an increasingly important issue with the increased use of HMDs in the rotary-wing cockpit.

During the early development of the IHADSS in the 1970s, considerable concern was voiced regarding the monocular design of the IHADSS. Visual issues such as the Pulfrich phenomena (apparent out of plane rotation of a moving target due to unequal binocular illumination), loss of stereopsis and depth perception, eye dominance, and binocular rivalry were the subjects of much discussion. In the late 1980s, numerous vision researchers intensified the concerns over the human visual system's response to viewing HMD virtual imagery and the possible impact on visual performance.[6-9] Between 1988 and 1990, three studies were conducted which seemed to confirm that pilots were experiencing some difficulties with flying the AH-64 using FLIR imagery presented on the IHADSS HMD.

In 1988, Hale and Piccione conducted an operational assessment of problems experienced with the IHADSS by the AH-64A pilot population.[2] A survey questionnaire was distributed to 52 AH-64A pilots at Fort Hood, TX. The questionnaire consisted of 37 items that addressed various human factor-engineering aspects of the PNVS and IHADSS systems. In addition to the written questionnaire, verbal discussions were held with each pilot. The major areas of interest in the survey were: perceptual inaccuracies, FLIR image quality, symbology, monocular viewing, spatial disorientation, and physical comfort. Based on pilot responses, FLIR quality, distance and size perception, ability to alternate attention between eyes, unintentional alternation, and limited FOV were the major concerns reported.

About the same time, in 1989, Crowley surveyed 242 aviators flying either the Aviator's Night Vision Imaging System, an image intensification device, or the Apache IHADSS soliciting reports of visual illusions during flight.[3] Twenty-one (9%) of the respondents were Apache aviators reporting illusions or other visual effects with the FLIR sensor and IHADSS. The reports from the questionnaires were classified as either reports of degraded visual cues, static illusions, dynamic illusions, or miscellaneous reports. The most common degraded visual cue was impaired acuity (14%) and degraded resolution/insufficient detail; the most common static illusion was that of faulty height judgment (19%); the most common dynamic illusions were undetected aircraft drift (24%) and illusory aircraft drift (24%), followed by disorientation (14%) and faulty closure judgment (10%); the most common miscellaneous report was distracting symbology. Summaries of reports are presented in Tables 1 through 4.

Report	%	(n)
Degraded resolution/insufficient detail	14	(3)
Loss of visual contact with horizon	10	(2)
Impaired depth perception	10	(2)
Decreased FOV	10	(2)
Inadvertent instrument meteorological Condition (IMC)	5	(1)

Table 1. Reports of Degraded Visual Cues (n=21)[3]

Report	%	(n)
Faulty height judgment	19	(4)
Trouble with lights	5	(1)

Table 2. Reports of Static Illusions (n=21)[3]

Report	%	(n)
Undetected aircraft drift	24	(5)
Illusory aircraft drift	24	(5)
Disorientation ("vertigo")	14	(3)
Faulty closure judgment	10	(2)

Table 3. Reports of Dynamic Illusions (n=21)[3]

Report	%	(n)
Hardware-related problems		
Distracting symbology	14	(3)
Crew coordination problems		
Mixing FLIR and image Intensification	5	(1)
Physiological effects		
Dark adaptation effects	5	(1)

Table 4. Miscellaneous Reports (n=21)[3]

In summary, the questionnaire responses, although based on a very limited sample size (n=21), provided additional evidence that at least some Apache aviators flying with the FLIR sensor and IHADSS HMD were experiencing visual problems and illusions which were possibly degrading mission performance.

Prompted by the above studies and anecdotal complaints to Army flight surgeons, Behar et al conducted a three-part study to investigate possible long-term vision effects of using the IHADSS monocular HMD.[1] The first part of the study was a written questionnaire that served the purpose of documenting visual problems experienced by the local Fort Rucker, AL, Apache aviator training community (58 instructor pilots). The second part was a clinical and laboratory evaluation of the refractive and visual status of a sample of these aviators. The third part was an assessment of the diopter focus setting used by a random sampling of aviators in the field environment.

For the 58 Apache aviator questionnaires, 80% of the respondents reported at least one visual complaint experienced either *during* or *after* flight with the IHADSS. A summary of complaints is provided in Table 5. The most common complaint *during* flight was "visual discomfort." Over one-third of the respondents complained of experiencing headaches at least sometimes *after* flight.

	During flight (%)			After flight (%)		
	Never	Sometimes	Always	Never	Sometimes	Always
Visual discomfort	49	51	-	70	28	2
Headache	65	35	-	67	32	2
Double vision	86	12	2	89	9	2
Blurred vision	79	21	-	72	24	3
Disorientation	81	19	-	95	5	-
Afterimages	NA	NA	NA	79	19	2

Table 5. Percentage of Aviators Reporting Visual Symptoms During and After Apache Flight.[1]

In spite of the visual complaints reported in the questionnaires, the clinical and laboratory evaluation of 10 Apaches aviators found no statistical correlation between visual performance and visual complaints. In addition, there were no significant differences found between left and right eye performance. In summary, the study concluded that there were no significant deviations from normal visual performance on all the tests.

A possible explanation of some of the visual complaints was found in the diopter setting section of the study. This section measured the focus settings of 20 Apache aviators (11 student and nine instructor pilots) following their preparation for flight. Nine were measured under nighttime illumination conditions and 10 under daytime conditions. A range in focus settings of 0 to -5.25 diopters (mean of -2.28 diopters) was obtained. It was concluded that the required positive accommodation by the eye to offset the negative focus settings was a likely source of headaches and visual complaints reported during and after prolonged flights. No correlation was found between the focus settings and aviator age or experience; nor were there differences between instructor and student pilots, or day versus night.

The survey in the Behar et al study was limited in sample size (n=58) and included only instructor pilots.[1] In 2000, this basic survey was repeated for a much larger sample size (n=216) and wider range of Apache experience.[5] The year 2000 survey was a near complete duplication of the original 1990 survey and the Crowley visual illusion questionnaire combined, with added sections to inquire about helmet fitting and acoustic issues. This duplication allowed subjective comparison between aviator visual complaints and illusions across the 10-year period. In addition to the limited scope of the 1990 study, the new survey was desirable for the following reasons: (1) there was renewed interest in the presence of visual complaints with use of the monocular IHADSS, fueled by expanded fielding of the AH-64 Apache helicopter in the United Kingdom and other countries and (2) during this period, the flight track for AH-64 aviators had changed. During the early years of the AH-64 fielding, all AH-64 aviators were experienced aviators who had transitioned from other aircraft (primarily the AH-1 Cobra). In 1986, AH-64 aviators began transitioning directly from initial entry rotary wing training into flying the AH-64 Apache. And, as mentioned earlier, the respondents in the 1990 study were all experienced instructor pilots. The 2000 study included aviators with as few as 20 AH-64 flight hours.

The 2000 survey verified the continuing presence of visual problems for some Apache aviators. A summary of reported visual complaints is presented in Table 6.

	During flight				After flight			
	Never	**Sometimes**	**Always**	**NR**	**Never**	**Sometimes**	**Always**	**NR**
Visual discomfort	18.5	76.4	5.1	0.0	25.5	66.2	7.9	0.5
Headache	38.9	59.7	0.9	0.5	36.1	61.1	1.4	1.4
Double vision	93.5	6.0	0.5	0.0	93.1	4.6	0.5	1.9
Blurred vision	66.2	33.3	0.5	0.0	63.0	36.6	0.5	0.0
Disorientation	57.4	42.1	0.0	0.5	88.4	9.7	0.0	1.9
Afterimages	70.4	27.3	1.9	0.5	51.9	41.7	5.1	1.4

Table 6. Reported Vision Complaints for 2000 IHADSS Survey (expressed in percent)

The pertinent major conclusions from the newer survey were:

• There were sufficient data to indicate that responding Apache aviators flying with the IHADSS experience a relatively high frequency of a variety of visual symptoms; 92% of respondents reported at least one visual complaint/symptom either *during* or *after* flight.

• A comparison between findings in this survey and a similar one performed in 1990 showed subjective trend increases in the proportion of multiple visual symptoms to include visual discomfort and headaches both *during* and *after* flight with the IHADSS, for disorientation *during* flight, and for afterimages *after* flight.

• The frequency of complaints was not correlated to age or AH-64 flight experience.

• The data did not support any association between eye preference (dominant eye) and the number of complaints or the presence of unintentional alternation (switching) between the left, unaided eye and the right, aided eye viewing the IHADSS imagery.

• The two most reported static illusions were faulty slope estimation and faulty height judgment, reported by approximately three-quarters of the respondents. There was a high incidence of dynamic illusions reported, with six of the eight identified dynamic illusions reported by more than half of the respondents. The two most reported dynamic illusions were undetected drift and faulty closure judgment, reported by more than three-quarters of the respondents.

• When asked to provide additional comments, the single issue most strongly voiced by AH-64 aviators was the poor performance of the FLIR sensor. This survey does not allow the determination of what poor FLIR imagery contributes to the reported visual symptoms.

The background discussion above suggests that there may be some correlation between AH-64 accidents and the use of the PNVS sensor and IHADSS HMD. This study has as its primary objective the investigation of the possible role that the IHADSS HMD and PNVS may have played in AH-64 accidents. This includes the incidence of HMD induced visual symptoms, (for example, headache, blurred vision, double vision, etc), and the incidence of HMD and PNVS induced static and dynamic illusions, (for example, faulty height judgment, faulty distance estimation, etc).

Accident Database

The data analyzed herein were obtained from a search of the U.S. Army Risk Management Information System (RMIS) that was created in 1972 and is maintained by the U.S. Army Safety Center (USASC), Fort Rucker, AL. The USASC tracks three types of aviation accidents: flight, flight-related, and ground. A flight accident is one in which intent for flight exists and there is reportable damage to the aircraft itself. Intent for flight begins when aircraft power is applied, or brakes released, to move the aircraft under its own power with an authorized crew. Intent for flight ends when the aircraft is at full stop and power is completely reduced. Flight-related and ground accidents are not used by the USASC in calculations of accident rates. The rates reported herein adopt these criteria and include flight accidents only. Accident rates are based on the number of occurrences per 100,000 flight hours and provided per FY(1 Oct through 30 Sep). Accident frequencies and rates used in this paper cover the period FY85-FY-02 (first half, based on data entries made by 31 Mar 02).

Army aviation accidents are classified as Class A through E.[10] For the purposes of this study, Class D and E accidents are not included due to the large number and innocuous nature of these accidents with respect to aviation safety. Accident classes are based on criteria of number of fatalities, number and types of injuries, and equipment and collateral dollar costs. Accident class criteria have been revised three times since 1972. The most recent revision was that of 1 Oct 01 (FY02). There were a total of 217 AH-64A and 11 AH-64D Class A-C accidents for the period FY85 through the first half of FY02 (31 Mar 02).

The objective of this investigation was to look at the role that the IHADSS HMD and the PNVS/FLIR may have played in past AH-64 Apache accidents. Therefore, each accident (record) was scrutinized with respect to HMD use and/or PNVS/FLIR image quality influence.

Accident Cause Categorization

The RMIS database assigns each accident a primary cause in regards to contributing factors. These causal factors are: human error, materiel failure, and environment. An accident may be assigned more than one causal factor. A human error accident is defined as an accident where job performance, which differs from that which is normally required in a situation, caused or contributed to the accident. An example of a human factor error would be where an aircrew member inadvertently activated the chop switch during flight, causing the engines to idle. Environmental factors include conditions such as noise, illumination, bird strikes, and space/weather conditions that have an adverse effect on the performance of the individual or equipment, which causes or contributes to the accident. Materiel failure is when equipment: (1) stopped working entirely; (2) worked, but malfunctioned; or (3) has degraded to the point that machinery was unreliable/unsafe for continued use. Examples of this type of failure would be an engine overheating or main rotor revolutions-per-minute decay.

Table 7 shows the frequencies and percentages for the USASC attributed causal factors for *all* AH-64A and AH-64D accidents from FY85 through first half of FY02 (31 Mar 02). A review of Table 7 shows that the accidents were dominated by the “human error” causal factor, both alone and in combination with one of the other cause factors (66.3% for the AH-64A and 36.4% for the AH-64D. This observation is in agreement with a 1998 3-year review (FY95-97) of the safety performance of the AH-64, which concluded that human performance error was the primary causal factor for that period.[11] The study raised the question of the possible role of task saturation as a contributing factor. This was not a surprising possibility since, in addition to physically maneuvering around obstacles both on and off the ground, the aviator must pay close attention to numerous other sources of information such as from panel-mounted cockpit displays, the HMD, and audio/communication systems. Having to interpret pilotage and gunnery data from the cockpit displays or the HMD easily could contribute to task overload.

For the purpose of this investigation, the causal factors used by the USASC were too broad and could not provide insight into the role of HMD and PNVS use in each accident. Therefore, each AH-64A/D accident was reviewed and assigned to one of five types using a scheme developed for spatial orientation accident analysis by Durnford et al.[12] These types were defined as follows:

- *Type 1.* HMD and/or PNVS use was the major component of the accident sequence (which meant that all other contributory factors normally would have been overcome without mishap).

- *Type 2.* HMD and/or PNVS use was a subsidiary component of the accident sequence (which meant that other contributory factors would have led to a mishap in any case, but HMD and/or PNVS use made the accident sequence more difficult to deal with or the outcome more severe).

	AH-64A		AH-64D	
Casual factor(s)	**Frequency**	**Percent**	**Frequency**	**Percent**
Human error	123	56.7	3	27.3
Materiel failure	42	19.4	2	18.2
Environmental	6	2.8	0	0
Human error/materiel failure	17	7.8	1	9.1
Human error/environmental	4	1.8	0	0
Materiel failure/environmental	1	0.5	0	0
Human error, materiel failure/ environmental	0	0	0	0
Not classified	24	11.1	5	45.5
Total	217	100.0	11	100.0

Table 7. Frequencies and Relative Percentages of all AH-64 Flight Accidents by Attributed Causal Factor(s)

• *Type 3*. HMD and/or PNVS use was an incidental component (which meant that HMD and/or PNVS was used or was present but did not affect the outcome).

• *Type 4*. HMD and/or PNVS *not* in use.

• *Type 5*. HMD and/or PNVS use was unknown.

Type assignment was a measure of the indicated strength of contribution of HMD and/or PNVS use to the accident. The minimum standard for assigning a given accident to one of the above types was not, in all cases, one of absolute certainty but was one based on the opinions and views of the authors and subject matter experts. It is important to note that during the early fielding of the AH-64 Apache, there was an insufficient awareness on the part of accident investigation teams of the impact of the novel monocular IHADSS HMD design on aviator visual performance, situational awareness, etc.

After applying type assignment to all Apache accidents, there were a total of 93 AH-64A and 4 AH-64D accidents for the period FY85 through the first half of FY02 (31 Mar 02) for Class A-C accidents for which the HMD/PNVS was identified as in use (Types 1-3). There were 33 AH-64A and 5 AH-64D accidents in which use or nonuse of the HMD/PNVS was not recorded (Type 5). A thorough review of these unidentified accidents revealed that one AH-64A Class C accident should have been identified as an HMD/PNVS in-use accident. Therefore, the total number of HMD/PNVS in-use accidents analyzed in this study was 94 AH-64A and 4 AH-64D. The accident frequencies and associated percentages by USASC causal factors for these 98 accidents are presented in Table 8. For the AH-64A, the trend for the majority of accidents to be categorized as "human error" was maintained. Human error was found to contribute to 79.8% of AH-64A and 50% of AH-64D accidents where the HDU was in use. However, with only 4 AH-64D accidents to review, it would be inappropriate to generalize the AH-64D finding to the general population.

	AH-64A		AH 64-D	
Casual factor(s)	**Frequency**	**Percent**	**Frequency**	**Percent**
Human error	67	71.3	1	25.0
Materiel failure	7	7.4	0	0
Environmental	3	3.2	0	0
Human error and materiel failure	8	8.5	1	25.0
Human error and environmental	0	0	0	0
Materiel failure and environmental	0	0	0	0
Human error, materiel failure and environmental	0	0	0	0
None	9	9.6	2	50.0
Total	94	100.0	4	100.0

Table 8. Frequencies and Relative Percentages of AH-64 flight Accidents by Associated Causal factor(s) with HDU in Use

Types 4 and 5 accidents, in which the IHADSS HMD/PNVS was clearly indicated as not in use or use was unknown, were eliminated. The remaining accidents, those where HMD/PNVS use *was* indicated, are summarized by type and aircraft model in Table 9.

	Type 1	Type 2	Type 3
AH-64A	2	19	3
AH-64D	0	0	74
Total	2(2%)	19(19%)	77(79%)

Table 9. Summary of HMD In-Use Accidents by Type

Analysis of Accidents

After categorized by type, those accidents where the HMD was identified as a major or subsidiary component of the accident sequence (Types 1 and 2) were analyzed for causal fault factors. Table 10 provides a list of six major fault factors used to further characterize these accidents. These major factors were (1) display-related; (2) degraded visual cues; (3) static illusions; (4) dynamic illusions; (5) hardware problems related to PNVS/IHADSS; and (6) crew coordination related to PNVS/IHADSS use. The following paragraphs briefly describe and provide an example(s) of each major fault factor.

Display-related factors were those that encompassed issues relating to the interpretation of the display information or interaction(s) between the pilot and the HDU display. Four sub-factors were included as display related. These could be physiological, to include conditions such as diplopia (double vision), blurred vision, dark adaptation, etc. Another factor was the impact of the HDU fit and function on the available FOV. The factor of alternation (or rivalry) addressed situations where the pilot was either unable to optimally select between the two visual inputs or was subject to uncontrollable alternation of inputs. Degraded (insufficient) resolution referred to the failure of the display to provide the pilot with sufficient resolution to perform required tasks. However, a degraded display image also may have been caused by poor FLIR sensor operation or poor FLIR conditions (weather, time of day, etc), factors that are addressed below.

Accident fault factor
Display-related
Physiological causes
HDU impact on visual field/FOV
Alternation/rivalry
Degraded (insufficient) resolution
Degraded visual cues
Loss of visual contact with horizon
Impaired depth perception
Limited PNVS FOV
Inadvertent (IMC)
Static illusions
Faulty height judgment
Trouble with lights
Dynamic illusions
Undetected drift
Illusionary drift
Faulty closure judgment
Disorientation (vertigo)
Hardware problem related to PNVS/IHADSS
PNVS/FLIR sensor failure
IHADSS display/HDU failure
Design limitation
Crew coordination related to PNVS/IHADSS

Table 10. Fault Factors for Accidents with Types 1 thru 3

Degraded visual cues were associated with situations or conditions where there was partial or total loss of visual information. These factors included loss of visual contact with the horizon, impaired depth perception, limited PNVS FOV, or the onset of inadvertent IMC resulting from poor FLIR conditions.

Static illusion factors were associated with situations or conditions that could have contributed to an accident by virtue of causing a misinterpretation or misjudgment of available information during activities where there was no relative motion.[13] These factors were faulty height judgment and trouble with lights.

Dynamic illusions were the misinterpretation or misjudgment of visual information due to relative motion.[13] These factors were undetected and illusionary drift, faulty closure judgment, and disorientation (vertigo).

Hardware-related factors addressed PNVS FLIR or IHADSS system failures or malfunctions. Examples included inadvertent release of HDU, FLIR, or CRT display power supply failure, and FLIR gimbal lock-up. This category also encompassed design limitations of the PNVS FLIR, (for example, the PNVS sensor has a limited resolution defined by its thermal detector's D value [D-star, a measure of detectivity]) which could have resulted in the inability of the detector to be able to discriminate between two objects having a very small temperature differential.

Crew coordination factors related to the PNVS/IHADSS systems were the final major category used to further differentiate accident causes. An example of this type of incident would be having both members of the crew focusing on FLIR imagery at the cost of neglecting duties related to flying.

The 21 accidents in which the HDU/PNVS were suspected to have played a role were evaluated by both U.S. Army Aeromedical Research Laboratory (USAARL) researchers as well as by an experienced Apache pilot (who served as a member of the accident investigation team for many of the accidents in this study). Summaries of accidents were studied and a worksheet was designed to standardize the issues examined in each accident. Issues considered were display-related problems, degraded visual cues, illusions (both static and dynamic), hardware problems, and crew coordination issues (Table 10). Readers are cautioned that many of these factors are not mutually exclusive, and assignment of factors, while by no means arbitrary, is open to discussion.

A summary of the accident fault factors is presented in Table 11. The leading factors identified were those related to dynamic illusions, degraded visual cues, and crew coordination. Dynamic illusions, which included undetected drift, faulty closure judgment, and disorientation, were associated with 91% (19 of 21) of the accidents. Of these dynamic illusions, undetected drift was singularly identified as the most common illusion, with 52% (11 of 21) of all accidents associated with this problem. The second most frequently found major causal factor was degraded visual cues, with it being associated with 62% (13 of 21) of the accidents. This was followed by the crew coordination factor found in 57% (12 of 21) of the accidents.

The remaining and less reported causal factors were hardware-related (48%), display-related (33%), and static illusions (24%). The most common hardware-related factor was associated with the PNVS FLIR sensor, degraded resolution was most common for display-related, and faulty height judgment was the sole static illusion.

Discussions and Conclusions

The IHADSS used on the AH-64 Apache helicopter is a very unique system. While presenting a somewhat similar flight

Accident Fault Factor	Number of accidents in which the factor was determined to be present/contributing	Totals by accident fault factor
Display-related		7
Physiological causes	0	
HDU impact on visual field	1	
Alternation/rivalry	1	
Degraded (insufficient) resolution	5	
Degraded visual cues		13
Poor FLIR conditions	4	
Loss of visual contact with ground	2	
Impaired depth perception	4	
Limited PNVS FOV	1	
Inadvertent IMC	2	
Static illusions		5
Faulty height judgment	5	
Trouble with lights	0	
Dynamic illusions		19
Undetected drift	11	
Illusionary drift	0	
Faculty closure judgment	5	
Disorientation (vertigo)	3	
Hardware-related problems PNVS/IHADDS		10
PNVS/FLIR sensor failure	5	
IHADSS display/HDU failure	0	
Design limitation	5	
Crew coordination related to PNVS/IHADSS	12	12

Table 11. Summary of Fault Factors for Accident Types 1 and 2

scenario to that of flying with image intensification-based night vision goggles, it differs in several ways. First, it is a monocular system, presenting the FLIR imagery only to the right eye. Second, the flight imagery is presented in a limited 30° x 40° FOV. Third, the perspective of this imagery is exocentric in location, since the FLIR sensor is located several feet forward and below the actual pilot eye position. And, lastly, the information content of the FLIR imagery is based on an entirely different part of the spectrum, 8-12 microns, than is normally presented to the human visual processing system. All of these factors result in the AH-64 pilot attempting to fly a sophisticated aircraft under very unusual conditions.

The investigation of any accident involves hundreds of factors, and it is a challenging task to attempt to keep up with the continuing and ever increasing change in technology in Army rotary-wing aircraft. For this reason, it is not always possible to identify and capture all of the important and necessary data needed to fully understand the impact and role of novel systems such as the IHADSS/FLIR system in accidents. Consequently, current accident data reporting forms do little more than record whether or not night vision devices, such as the IHADSS, were in use. Any additional, but pertinent data, must be sought, interpreted, analyzed, and recorded by accident investigators in an unstructured format. This often has resulted in insufficient data to fully characterize the role and impact of the IHADSS in AH-64 accidents. This is especially true regarding information that might be related to display image quality, degraded visual cues, and both static and dynamic illusions.

Of the 228 accidents reported during the time period FY85 to FY02 (through 31 Mar 02), fewer than half (43%) of the

AH-64 accidents (both A and D models) involved the use of the IHADSS HMD. Of all AH-64 accidents studied, only 9.2% (21 of 228) were categorized as ones in which the HMD and PNVS played a major or subsidiary role in the accident sequence itself. When only Type 1 accidents are considered, those in which the IHADSS/FLIR system was identified as the *major* contributor, they represented less than 1% of all AH-64 accidents and only 2% of accidents where IHADSS use was identified. While these were relatively small percentages, the 21 combined Type 1 and 2 accidents did represent 21% of the 98 accidents in which the IHADSS was identified as in use.

The most frequent causal factor in all of the accidents studied was dynamic illusions (91%), with undetected drift being the most common type. As an example, in accident six, a Class C/Type 2 accident, the aircraft was allowed to drift into a tree because the student pilot failed to adequately monitor instruments, and the instructor pilot misjudged the position of the aircraft in relation to the trees (height judgment, 24%).

The second most frequent causal factor was degraded visual cues (62%), which was distributed across multiple sub-factors with poor FLIR conditions (19%) and impaired depth perception (19%) being more common. This was exemplified in accident 14 (Class B/Type 1) where the crew was operating under poor FLIR conditions (following 4 days of rain). While trying to maintain a hover, the poor PNVS/FLIR visual cues, in conjunction with a lack of depth perception, prevented the crew from detecting the presence of trees, and failing to detect aircraft drift, allowed the main rotor blades to make contact with the trees.

In 57% of the accidents, inadequate crew coordination was identified as a causal factor. For example, in accident 13 (Class A/Type 2), while transitioning from an air to a hover taxi, the pilot in command, unable to perceive ground references and determine altitude and drift, failed to request assistance from the pilot, who was troubleshooting the PNVS. Consequently, the aircraft hit the ground in an 85º-left yaw attitude. In Aug 02, the USASCs aviation safety risk management magazine, Flightfax, published a review of the AH-64's safety performance for fiscal years 1998 through 2002 (as of 12 Aug 02).[14] In this review, failure in crew coordination was an often-cited contributing factor.

The presence and frequency of the above causal factors in the AH-64 accidents studied are consistent with the findings of Crowley and Rash et al.[3,5] Both studies listed pilot-reported problems associated with dynamic illusions, particularly undetected drift. Poor sensor performance was also noted in Hale and Piccione's study and Rash et al.[2,5] However, it is worth noting that the two most prevalent causal factors/sub-factors were crew coordination and undetected drift, conditions not exclusive to the AH-64 Apache. Crew coordination is a frequent U.S. Army aviation safety topic of discussion.[15] A review of the USASC database for the period FY99 through 1st quarter FY02 showed that a total of 13% Class A-C accidents involved crew coordination. The constant need to "tweak" the FLIR sensor output and its display was shown to contribute to the workload in the cockpit and often served as a distracter from other flight duties, a scenario which calls for increased crew coordination.

Some of the causal factors were directly tied to the AH-64 aircraft, and more specifically to the IHADSS/PNVS. Most of these instances were associated with the quality of the FLIR imagery. The most recent and extensive survey of visual problems and issues associated with the AH-64 HMD (Rash et al) found FLIR quality to be one of the strongest concerns among AH-64 pilots.[5] Designed during the late 1970s, the AH-64s thermal sensor in combination with the IHADSS provides an equivalent Snellen visual acuity of only 20/60.[16] It is hoped that the FLIR sensor upgrade planned for the near future comes to fruition.

In summary, while the presence and use of the IHADSS HMD present a very unique situation in the AH-64 Apache cockpit, it does not seem to be a major contributor to accidents. However, it does seem to serve as one more factor that increases workload and requires increased crew coordination. Of greater impact to safety is the inability of poor FLIR sensor performance to provide pilots with sufficient resolution. This poor performance is greatly increased during and following periods of environmental conditions that render the FLIR sensor ineffectual. The resulting lack of image quality significantly increases visual workload.

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Spatial Hearing, Hearing Impairments, and Hearing Protection

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Spatial hearing is an important function in human perception and has been essential to the survival of the species. It has helped hunters to find food and stay clear of predators. Spatial hearing is largely based on the fact that our brain can detect differences between signals in our left and right ear; for instance, differences in interaural arrival time, phase, and intensity. Hearing impairments generally affect spatial hearing ability in a negative way, but the degree depends on the type of hearing impairment. Hearing protection devices (HPDs), intended to minimize noise-induced hearing loss, can also interfere with spatial hearing. Current spatial hearing research at the United States Army Aeromedcal Research Laboratory (USAARL) focuses on (1) potentially degrading effects of HPDs; (2) spatial hearing degradation caused by noise-induced hearing loss; and (3) spatial properties of electro-acoustic auditory displays to be used in aviation.

Introduction

Zeno of Citium (3d Century B.C.) once said that nature has given us two ears and one mouth, so that we may listen twice as much as we may speak.[1] Although these wise words may still be as true today as they were then, modern science has greatly clarified the perceptual advantages of listening to our environment with two ears. Compared with *monotic* listening (with one ear only), *dichotic* listening (with slightly different signals in each ear) allows us to locate sound sources, detect movement of sound sources, or focus on a particular sound source in the midst of other competing sound sources.[2] Spatial hearing has been an important asset for survival to the species, since it allowed man as well as many animals to locate impending danger and potential food sources from a safe distance. In modern times, this translates into our ability to perceive the direction of an approaching vehicle in busy city traffic, or the ability of a dismounted Soldier to locate the position of an approaching enemy.

Spatial hearing can be achieved because air pressure waveforms in the left and right ears are almost always slightly different. In a sense, it resembles spatial vision, which is mediated by small differences between retinal images. When, for instance, a sound source is located at an 11 o'clock position with respect to the head, its sound will arrive earlier in the left ear than in the right ear because of the path length difference. For the same reason it will also be somewhat more intense in the left ear, particularly at high frequencies with wavelengths that are smaller than typical dimensions of the human head (for a reference, the wavelength of a 1000-Hz tone is about 1 foot). Extensive research has shown that the human auditory system is capable of (1) separating sound into different frequency bands and (2) computing interaural time and interaural intensity differences for each frequency band.[3]

If a sound source is located straight ahead, straight behind, straight above, or anywhere in the so-called "mid plane," there is, in principle, no interaural time or intensity difference between left and right ear signals. Therefore, if the human head and ears are modeled as a perfect sphere with two holes of opposite location, we could never differentiate between sound source locations in the mid plane. Our ability to distinguish sounds coming from different directions in the mid plane, at least to some extent, is attributed to the fact that we have ear shells attached to our head. These ear shells (Lat: pinnae) have a particular unique shape for each individual person. Their shapes determine a reflection pattern, boosting some frequencies and attenuating others, with the result that the incoming sound spectrum obtains a particular coloration. Details of this coloration depend on the sound's angle of incidence, providing an indirect cue to the brain as to the direction of a sound source. It appears obvious that the brain must learn the relationship between sound coloration and sound source location, probably some time during infancy. Later in this article we will discuss how the acoustic action of the human pinna can be simulated electronically, so that it becomes possible to listen to sounds through someone else's outer ears. The effect is quite amazing. Not only does everything sound in a different overall timbre, but sounds are also more difficult to localize, particularly the vertical positions. There is recent evidence that, after some time, the brain can adjust to an artificially altered spatial auditory map, just as a world that has been turned upside down by prism glasses will turn right side up again after a while.[4] Finally, the laws of physics tell us that the pinna coloration effect can only happen for high frequencies, where wavelengths are smaller than typical pinna dimensions. Measurements show that the frequency range involved is everything above 4 kHz.

Based on all considerations so far, some predictions can be made of how specific hearing impairments may affect our spatial hearing ability. Because perceptual sound source elevation is, for the most part, mediated by high frequency pinna cues, we can expect that people with severe high frequency hearing losses (for example, presbycusis patients) will have difficulty determining the correct elevation of a sound source. On the other hand, such people may be quite able to determine the correct azimuth direction of a sound because this process is, for the most part, mediated by interaural time differences in low frequency bands (below 1 kHz). Conductive hearing losses, which are typical for (for example, otosclerosis patients) can, on the other hand, seriously interfere with a person's ability to determine a source's azimuth.[5] This is because, when the conductive loss is sufficiently severe, the ratio of bone-conducted over air-conducted sound increases. Since sound in bone travels much faster than sound in air, interaural time differences will become very small, eliminating interaural time difference as a cue for azimuth discrimination. In fact, if one considers spatial hearing performance as a function of hearing disorder, patients with noise-induced hearing losses rank relatively high.[5] The U.S. Army employs, or has employed, many Soldiers who suffer from this type of hearing loss as a result of exposure to gunshot, vehicle, or helicopter noise. As an indication of the magnitude of the problem, the U.S. Army compensated more than 156,000 veterans for acquired hearing losses in the year 2001, at a cost of $226,496,520.[6] This figure keeps climbing every year. For this reason, research at the USAARL focuses on (1) appropriate hearing protection that will cause minimal interference with military operations and (2) electronic communication and audio displays with spatial features for use in helicopters, tanks, and other military vehicles that can be properly perceived by people with noise-induced hearing losses.

Some Basic Facts

The human auditory system is very sensitive to minute changes in the interaural time relationships between left and right ear signals. If one starts out with identical noise signals in both ears, presented through headphones, the perceived noise image will be exactly in the center of the head. Under ideal laboratory conditions, a place shift of the noise image can be heard if one signal is delayed with respect to the other by as little as 15 μs. Without any special acoustic laboratory equipment, one can test this by connecting both ears of a willing subject with a loop of PVC tubing behind the head and tapping sequentially with a pencil on the tubing at the center and at a place somewhat off center, either to the left or right. For an off-center distance of 0.5 cm, subjects can usually tell consistently whether the second tap went left or right. The path length difference in this case is 1-cm which, given a 340 m/s speed of sound, translates into an interaural time difference of about 30 μs.

With plain trigonometry, one can show that, as long as a sound source is much further away than the typical interaural distance of 15-cm, the relationship between the difference in path length from a sound source to, respectively, the left and right ear, is approximately given by the equation:

$D = B \sin \alpha$, where D is the path length difference, B is the distance between left and right ear, and α is the horizontal angle of the source measured from the direction straight ahead (zero azimuth). Using this formula, and assuming a barely detectable interaural time difference change of 15 μs (which is equivalent to a differential path length change of 0.5 cm), one finds that straight ahead we should be able to detect an angular source position change of about 2 degrees. Off to the side, at 90-degree azimuth, the path length difference to the two ears obviously equals the interaural distance, consistent with the formula. To obtain a change of 0.5 cm in this path difference, the sound source has to move about 15 degrees (to the 75- or 105-degree position). Hearing experiments with loudspeaker arrays mounted in an echo-free chamber, as reported in the literature, have validated these predicted figures.[3] Minimum audible azimuth angles straight ahead are typically about 2 degrees, degrading to as much as 15 degrees off to the side. That is why it makes sense to turn one's head in the direction of a sound if one wants to detect movements of the source.

The brain can keep track of interaural timing information only for frequencies up to about 1000-Hz. Beyond that frequency, the existing synchrony between the acoustic signal and the neural code in the 8th nerve, which is the connection between the inner ear and the brainstem, rapidly deteriorates so that the brain no longer obtains the required information. Fortunately, however, when frequencies reach 2000-Hz, their wavelengths become smaller than the head size, resulting in a "head shadow" effect. This effect causes sound in the ear that is closer to the sound source to be somewhat more intense than sound in the other ear. The interaural intensity difference is, again, a powerful indicator to the brain as to the direction of the sound source. Interaural intensity differences for laterally positioned sources can be as large as 20 decibel (dB) for frequencies beyond 4 kHz, while for frequencies below 1000-Hz, they are smaller than 5-dB.* For detection of a minimal change, the interaural intensity difference has to change by an amount between 0.5 and 1.0 dB, dependent on sound frequency. Comparison of physically measured interaural intensity differences with auditory source localization performance results appears to confirm that interaural intensity

*A dB is a logarithmic unit, making sound power to double for every 3-dB increase. The perceived loudness, which is a subjective attribute of a sound, roughly doubles for every tenfold (or 10-dB) increase of physical sound power.

differences are the principal cues to source location for frequencies between 1500-Hz and 6000-Hz.[3]

Finally, if one considers sound source locations outside the horizontal plane and assumes that the head has perfect spherical symmetry (if torso and pinna effects are ignored), it follows that interaural time and intensity differences should not be affected when a sound source is rotated around the axis connecting the two ears. Rotation of an azimuth vector determines a so-called "cone of confusion," a 3-dimensional (3-D) surface on which all sound source locations yield the same interaural time and intensity differences. (More precisely, such cones are actually two-sheet hyperboloids since those are the exact mathematical loci of all points having a constant difference in distance to two focal points.) Perceptual location ambiguities along cones of confusion really do exist, the most notorious being front-back confusions. It needs no explanation that a front-back confusion could be fatal for a Soldier involved in a ground battle. Fortunately, this type of ambiguity is, to a large extent, resolved by nonsymmetric elements in the geometry, such as torso effects, pinna effects and, most importantly, head movements during an observation.

Virtual 3-D Audio through Headphones

The classical way of presenting real spatial audio through headphones is to use a dummy head for the sound recording. Such a dummy head has an average human torso and head size, has similar acoustical reflection and absorption properties as the human body, is equipped with outer ears similar in shape to the average human ear, and has microphones mounted at the end of each ear canal. This way, all interaural signal differences that are experienced by a listener positioned in a sound field will be preserved in the electronic signals recorded from the dummy head. This method yields excellent spatial sound quality, but also has some disadvantages. Once recorded, the listener's spatial perspective cannot be changed during playback. Head movements have no effect, since the entire sound field will move with the head. Typical spatial ambiguities may remain unresolved, often resulting in a sensation that the sound is inside the head rather than outside.

A very powerful modern technique is the use of so-called "head-related transfer functions" or HRTFs.[7] A potential listener, with small microphones inserted in the entrance of both ear canals, is seated in a test chamber. For most systems, this test chamber must be echo-free, but some modern systems allow an ordinary room with reflecting walls. A test sound, usually a burst of noise, is emitted from a speaker that can be moved to various positions around the listener. Using the emitted sound signal and the signals recorded in the left and right ear, the acoustical transfer functions between the sound source location and both ear canals can be computed and stored. By repeating the measurements for many different sound source locations, typically at a constant distance from the listener's head, a complete spatial auditory map of transfer-function pairs can be obtained. During playback through headphones, each of these transfer-function pairs is used as a filter to place an electronic sound source (for example a monaural recording of an instrument, or a synthesized sound file) at any designated location in the listener's virtual auditory space. Even the natural effects of head movements can be simulated by electromagnetic position tracking of the headphones. When a head (phone) movement is detected, a different pair of filters is selected to compensate for the move, with the result that the sound field is experienced as stationary, independent of head movements. Comparisons of subjects' sound localization and spatial discrimination performance in real and virtual sound fields have shown that, with the correct simulation technique, there is hardly any performance degradation between real and virtual presentation.[7]

Some Useful Applications

There are many useful applications of spatial audio to enhance military operations. An old trick, known for more than half a century, is to connect the left and right headphones used in airplane cockpits in anti-phase. This causes normal, monaural radio messages to be lateralized (to sound on the sides of the head), while engine noise that is mostly in-phase for both ears will sound in the center of the head. The result of this trick is a 6-dB lower speech reception threshold, allowing a much weaker radio signal still to be heard and understood over the engine noise. A more sophisticated modern version of this trick is a virtual simulation of the so-called "cocktail party" effect.[2] Speech messages received over the radio are given a specific spatial location by sending appropriate HRTF information along with the message. This way, different locations can be assigned to messages that are broadcast simultaneously. The result is that the listener can focus on any of the incoming messages, ignoring all the others. If the broadcast were monaural, all simultaneously sounding messages would be virtually unintelligible.

Another type of application is to attach a spatial dimension to warning signals to warn a pilot about an approaching missile or hostile aircraft, or to warn a driver of a vehicle for approaching objects that might pose a danger. One could also think of a navigation signal that provides a direction for a pilot to head for in a case of spatial disorientation. This type of application puts a much heavier demand on a virtual 3-D audio system. Unlike the examples of the previous paragraph, these applications require the system to produce virtual signal locations that are true in an absolute sense. Any erroneously perceived sound source location, resulting from front-back confusions or "cone of confusion" ambiguities, would almost certainly lead to disaster.

A 3-D sound system used for this purpose must therefore be extremely robust for every potential user.

Current Research at the USAARL

Spatial hearing research currently being conducted in our laboratory makes use of the AuSIM Inc HeadZap™ and GoldMiner™ virtual audio systems to measure individual HRTFs and to generate simulated 3-D sound for listening experiments. The physical layout of the HeadZap™ system is illustrated in Figure 1. It is designed for use in an ordinary non-sound-treated room. Most listening experiments are performed in a double-walled sound-insulated chamber, with subjects listening to sounds through headphones.

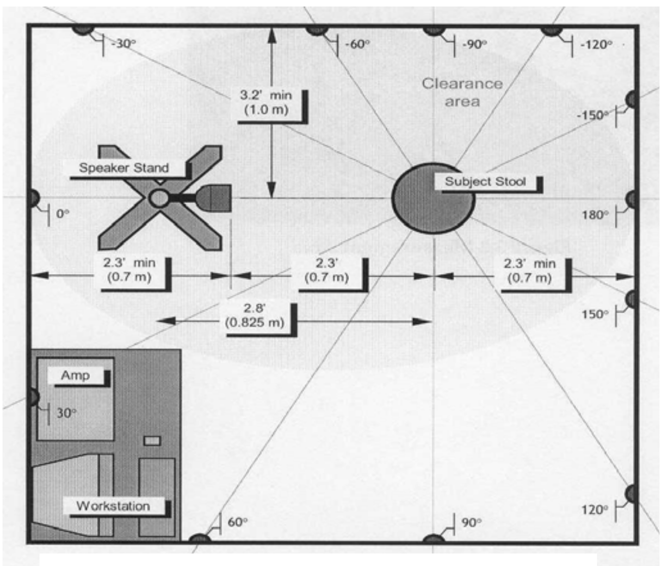


Fig 1. Typical layout of AuSIM3D "HeadZap" measurement system.

Experiments focus on two types of performance tasks. One concerns spatial discrimination and is, in fact, a measurement of minimum audible angles as described earlier in this article. For proper performance in this task, the virtual audio system does not have to provide a spatial map of sound source locations that is true in the absolute sense, since only a *change* in location of a sound has to be detected. The other type concerns absolute localization of a sound source, and requires mediation of a virtual spatial audio map that is identical to the one provided by our natural, nonoccluded ears. In both types of experiments, the principal research questions are:

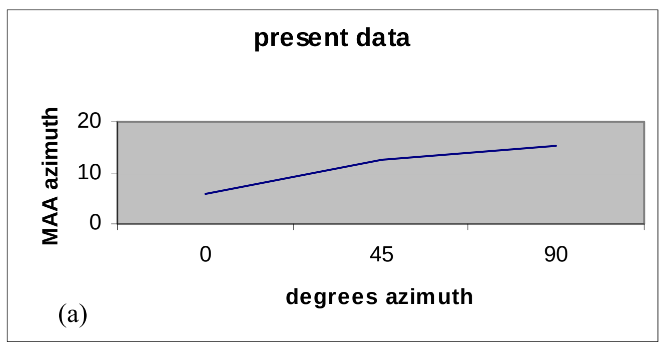
- Does the electronic virtual 3-D audio system yield the same performance as can be achieved in a natural acoustic free field?

- What is the added value of measuring customized HRTFs for each listener, compared with the use of generic HRTFs measured on a single dummy head?

- Are degradations in spatial hearing performance caused by noise-induced hearing damage similar for natural and virtual sound fields?

With respect to the first question, some preliminary answers have already been found. In a three-alternative forced choice discrimination experiment, subjects seated in a sound-insulated chamber and listening through headphones and using their own customized HRTFs, heard a sequence of three 200 ms white noise bursts on each trial. Two of these were placed at the same virtual location, and one at a (slightly) different location. The subject's task was to identify the "oddball" by clicking on one of three buttons shown on a liquid crystal display computer screen. To estimate discrimination threshold, an adaptive procedure was used. If two correct responses were given in succession, the distance between the oddball and reference stimuli was decreased, making the task on the next few trials more difficult. After an incorrect response, the distance was increased, making the task easier. This procedure converges to an interstimulus distance that, if used in a fixed nonadaptive run, would yield a 71%-correct score. Thresholds were measured for source positions between lateral left, front, and lateral right at zero degrees elevation, in 45-degree steps.

Preliminary results from one subject are shown in Figure 2a, where data for the left and right 90-degree sectors have been pooled. Similar data collected by McKinley et al who used an in-house developed auditory localization cue synthesizer are shown in Figure 2b.[8,9] Comparing results of these two figures,



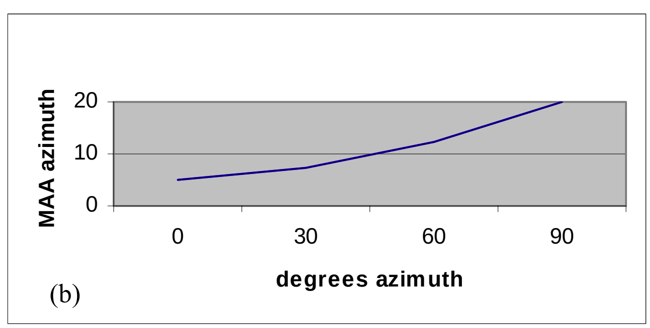


Fig 2. (a) Minimum audible azimuth angle, in degrees, in the frontal hemisphere obtained for one subject. (b) Results of a similar experiment taken from the literature.[8]

we can conclude that our preliminary spatial discrimination results appear to be in line with what can be expected of performance mediated by a virtual 3-D audio system. At the same time, however, a comparison of both data sets with free-field spatial discrimination performance found in the literature shows that free-field thresholds are somewhat smaller than thresholds obtained with virtual systems.[10] This can be interpreted as a measure of imperfection in the spatial sound representation of virtual 3-D systems.

An absolute sound localization experiment also was performed using both natural free-field and virtual sound field presentation. For free-field measurements, subjects were seated in a dark echo-free chamber while sounds were presented through a loudspeaker that was moved in the horizontal plane by a computer-controlled robot arm. For virtual presentation, subjects were seated in a sound-insulated room and were presented sounds through headphones filtered with their own customized HRTFs. In both cases, the sound source was a single 200 ms burst of white noise presented at some arbitrary azimuth position in the horizontal plane. Subjects were asked to identify the perceived source direction by clicking with a hand-held position-tracked stylus on a passive plastic globe placed in front of them. Two sets of 24 stimuli, spaced 15 degrees apart, were presented in random order.

Figure 3a shows a scatter plot of results for one subject in the free-field condition, whereas Figure 3b shows comparable results for virtual presentation. For comparison, Figure 4 shows comparable results obtained by Wightman and Kistler on a single subject under similar free-field and virtual sound conditions.[7] There were, admittedly, some potentially important differences in experimental details. Data points shown in Figure 3 represent raw responses from individual trials, while

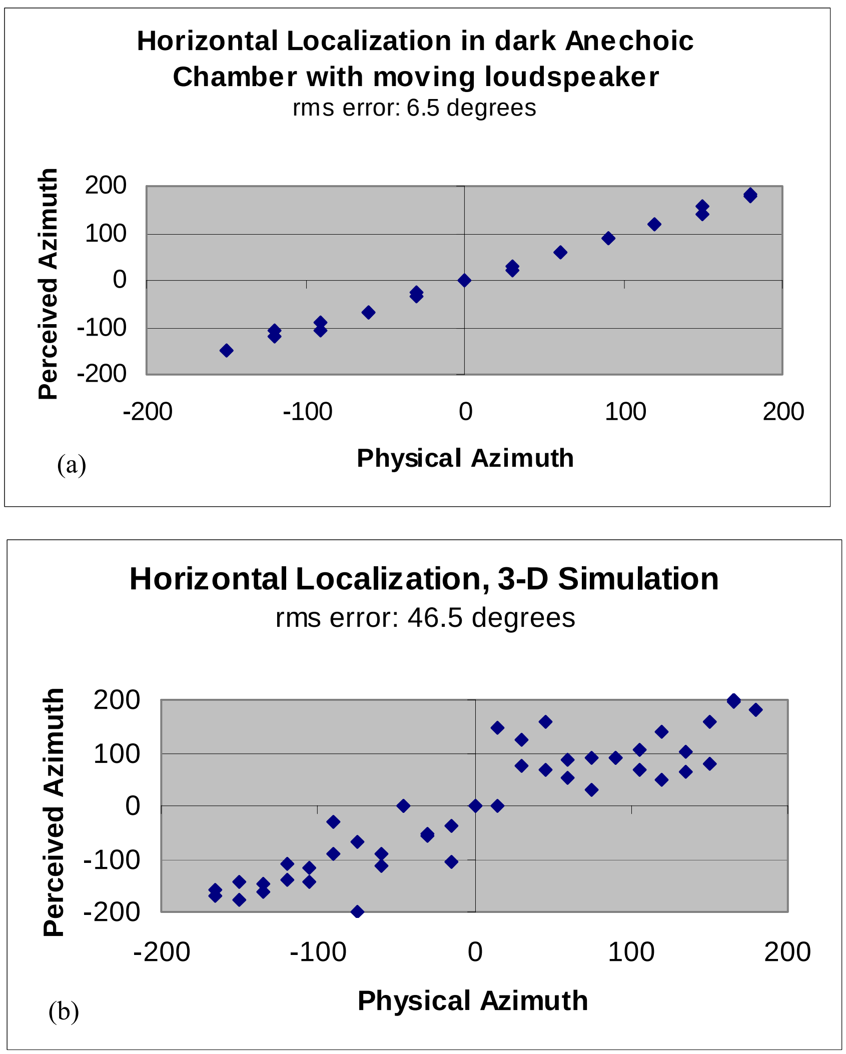


Fig 3. (a) Scatter plot of absolute localization results at zero-elevation, measured on one subject with a loudspeaker moving in a dark echo-free chamber. (b) Results from the same experiment and subject, using a 3-D audio simulation system.

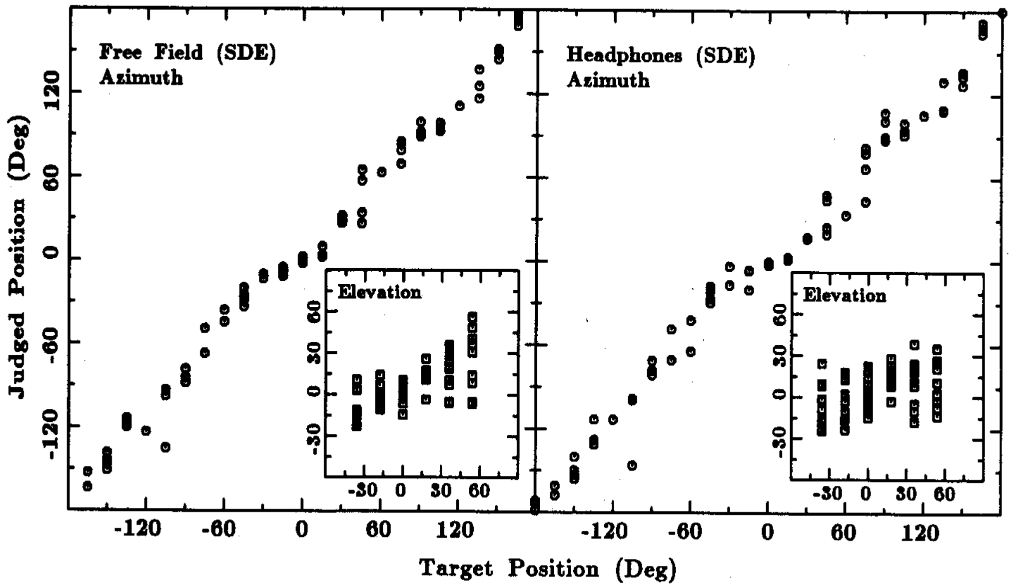


Fig 4. Results from an experiment similar to the one shown in Fig 3, taken from the literature.[7]

those shown in Figure 4 are averages of at least 6 trials. Also, the Wighman and Kistler experiment used stimuli of eight consecutive 250 ms noise bursts, whereas our experiment used single 200 ms bursts. Nevertheless, it is clear that the difference in data scatter between panels is much larger in Figure 3 than in Figure 4. This can also be seen in the average (rms) error increase from 6.5 to 46.5 degrees shown in Figure 3. Whereas Wightman and Kistler found only limited performance degradation in going from free-field to virtual sound presentation conditions, results of the present study show substantial degradation. Subjects informally complained about never perceiving sound sources really out in front. This lack of "externalization," particularly in the forward direction, appears consistent with the data shown in Figure 3b, where there seem to be fewer "front" than "back" responses.

Discussion

It is evident that absolute localization performance obtained with the present virtual 3-D audio system is not sufficiently robust and reliable to be applied to navigation signals, directional warning signals, or situational awareness aids. It is not clear at this point to what extent the insufficiency of the system represents programming errors that can be fixed by debugging, or to what extent it is a consequence of basic design decisions.† Unfortunately, there are no complete and objective performance tests that show whether 3-D audio simulation systems operate correctly and, if not, why and where they fail. Human perceptual performance based on system output is the only indication we have, so far, to assess proper optimal functioning of these systems.

A likely reason why discrimination performance appears normal is the fact that a spatial discrimination task requires only sensitivity to a change in a spatial pattern, without the need for an absolute reference. Therefore, one would expect discrimination performance to be the same, no matter whether the sound simulation is mediated by one's own, someone else's, or generic dummy head HRTFs. The same holds true for simulation of the cocktail party effect. We expect the AuSIM simulation system to perform quite adequately when used to suppress informational masking of simultaneous speech events that typically occur on shared-frequency radio communication channels.

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†Just before this article went to press, the AuSIM Inc president (William L. Chapin) paid a work visit to the USAARL where performance of the HeadZap™ and GoldMiner™ systems was thoroughly examined and, to the extent possible, debugged on the spot. Subsequent HRTF and absolute localization measurements, made on Mr Chapin and the author, resulted in rms errors of 6.2 and 7.6 degrees, respectively, for sound localization in the anechoic chamber, and 25 and 26 degrees, respectively, for sound localization in the AuSIM-simulated field.

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Warfighter Biovibrations

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The human body vibrates very gently through such mechanisms as postural and homeostatic maintenance, yet swings very coarsely during high activity processes such as walking and running. Popular culture is replete with references to our intrinsic hum through such phrases as "good vibrations" and "feeling buzzed." Macro movements were first recorded in the 1920s by Szymansky to quantify sleep duration. Low-level human microvibrations were first described in 1962 by Rohracher, who considered them a possible manifestation of resting muscle activity.

The forces associated with human motion, including both macro(gross), and microactivities, can be measured by accelerometry. More specifically, the study of motion and vibration in humans is called actigraphy. Research has shown actigraphy to be extremely reliable in discerning sleep from wake, and Medical Research and Materiel Command is researching models that use actigraphically-measured sleep to predict cognitive performance. Sleep measurement and performance prediction modeling is under continued evaluation for possible inclusion into both the Warfighter Physiological Status Monitoring and the Future Force Warrior programs. An actigraph on a Future Force Warrior would be used to discern motion associated with waking activities, and with specific knowledge of time spent awake verses time asleep, an algorithm would then be applied to predict an individual's relative alertness.

Studies at Walter Reed Army Medical Center (WRAMC) and Walter Reed Army Institute of Research (WRAIR) recently have shown heart rate, breathing, and life cessation within the actigraphically-measured biovibration signal.[1] This article discusses human biovibrations, the physiological monitoring applications of actigraphy currently under investigation in the Army Medical Department, and suggests potential future research paths.

Background

Actigraphy was originally developed in the 1920s to objectively measure and quantify sleep based on body movements. The first such study was performed by Szymansky, who constructed a device that was sensitive to the gross body movements of subjects as they lay in bed.[2] However, the advent of electroencephalograph (EEG) recording and its application to sleep, along with the development of EEG-based polysomnographic (PSG) standards for the scoring of sleep stages, resulted in a shift away from movement-based measurements of sleep.

Wrist-mounted actigraphy was developed in the 1970s and 1980s at WRAIR. Wrist-mounted actigraphs were based on technological advances that, for the first time, made long-term portable measurement and recording of movement data feasible.[3] This resulted in a resurgence of interest in movement-based measurement of sleep.

The primary research question: Are actigraphic measures of sleep/wake state both reliable and valid in comparison to the EEG gold standard? Several validation studies, using different actigraph scoring algorithms, employing subjects with various age ranges, sample sizes, and subjects with sleep and/or movement-related disorders were performed.

An early pilot study to address validation issues was conducted by Kripke et al.[4] Using five normal subjects, they reported excellent agreement between actigraphically-derived, manually scored and polysomnographically-determined measures of sleep duration. They reported a correlation coefficient of 0.98 – better than the typical 0.90 correlation between two well-trained individuals using PSG scoring method. Webster et al also published the first algorithm that could be used to automatically score actigraphic data.[5] The latter was an important step because up to that point the labor-intensive and tedious task of manually scoring actigraphic data on 30 second epoch-by-epoch bases at least partially obviated the advantages of the data collection technique. Figure 1 shows actigraphically determined sleep and wake using current algorithms. The actigraphy counts are based upon 30-second epochs. The sleep/wake score per epoch is shown below the actigram.

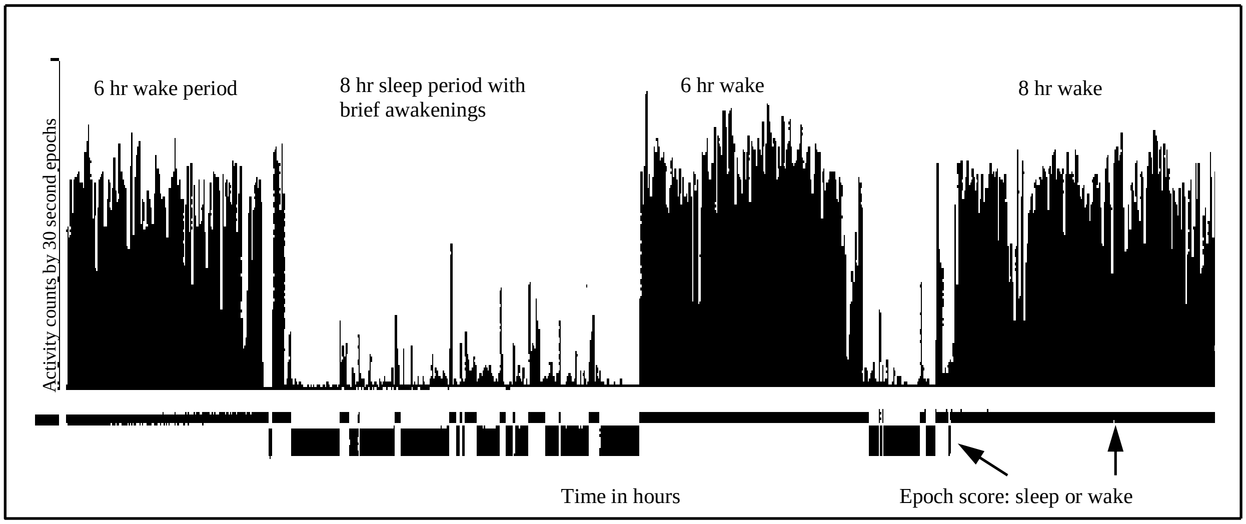

Fig 1. Conventional actigraphy with sleep scoring algorithm applied over a 28-hour period. Activity within each 30-second epoch is counted. An epoch is scored as wake if an activity is above a preset threshold and as sleep if activity is below that threshold. Using current algorithms, an individual sleeping in a moving vehicle would be considered awake, and an individual in a coma would be considered asleep.

Standard (conventional) actigraphic design represents an optimization of past technology based on two key considerations: (1) durable and reliable motion sensing that has the appropriate sensitivity and specificity to support algorithms that detect sleep/wake state transitions and (2) meeting requirements for size, weight, power, and computational capacity in a user-accepted device of reasonable cost. Current actigraphs are the size of small wristwatches and can collect data for many months on a single battery.

Advanced Actigraphy and Life Signs Data

Under a 2001 Phase I Small Business Innovation Research grant, a wrist-worn prototype of hardware, firmware, and sensor was developed to accurately detect and quantify sinusoidal respiration waves. Current efforts in developing Future Force Warrior actigraphs involve development of a general-purpose ballistic actigraph, one that will work across a broad range of signal waveforms. This Advanced Digital Signal (DSP) actigraph will allow recording and characterization of individual movements and patterns of movements, without destroying the information contained within them. Such features as duration, waveshape, amplitude, and component frequencies may be used to describe movements as they occur. These features may be saved and analyzed in relation to sleep, fatigue, exposure to neuro-motor toxins, or specific environmental conditions such as severe cold or high wind conditions.

Current, state-of-the-art actigraphy attempts to utilize detailed accelerometric information which had been previously discarded. Studies at WRAMC are demonstrating the very low-level displacement ballistographic signature of the heartbeat. Deuchar originally described the arterial pulsations as ballistocardiography.[6] Low frequency breathing movements from analysis of the signal within a 0.1 to 3 Hz bandwidth (Figure 2) and the ablation of these signals when the heart and ventilation is stopped (Figure 3) are also seen. When the band-pass filters are configured to record motion in the 0.1 to 9 Hz frequency range and sensitivity is maximized, the actigraph registers nonzero counts continuously, so long as the device is being worn. This activity may be considered a life signs signal, and may be related to the microvibrations described by Rohracher.[7] According to Rohracher, a low-level tremor occurs in the frequency band of 7.5 to 12.5 Hz, and is readily detected by actigraphy. Bircher et al considered that alterations in these microtremors may be related to body stress levels.[8] Our hypothesis is that these microvibrations may be the peripherally measured motion associated with rhythmic physiologic activities, including heartbeat, gastrointestinal activity, and respiration, and as such may be an essential indicator of life. Microvibration patterns may be specific enough to serve as signatures of individual humans.

The difficulty in distinguishing physiological signals from artifact has proved challenging in the applications of actigraphy in clinical medicine. For example, attempts to apply actigraphy in Parkinson's patients identified difficulties in distinguishing between tremor, slow movements (bradykinesia), rigidity, and normal ambulatory activity. Van Someren et al designed and tested techniques to specifically detect and quantify Parkinsonian tremor, with some success.[9,10] Due to technical limitations of earlier versions of the actigraph, their versatility in response to varied settings and fluctuations in tremor characteristics were restricted. As a rule, current objective

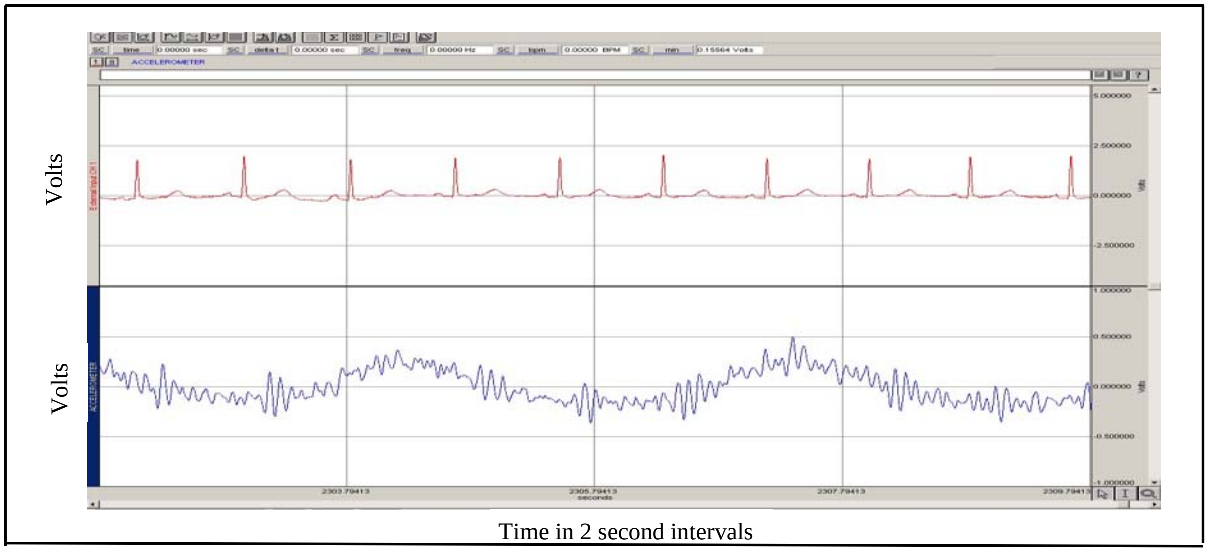

Fig 2. Electrocardiogram (ECG) (upper panel) and DSP actigram (lower panel) in a Walter Reed patient under deep anesthesia, time synchronized over a 10 second period. DSP actigram shows ballistocardiobursts called W-waves following ECG-recorded heart rate by several milliseconds, microtremor as high frequency low amplitude background activity, and respirations as low amplitude low frequency sinusoidal waves.

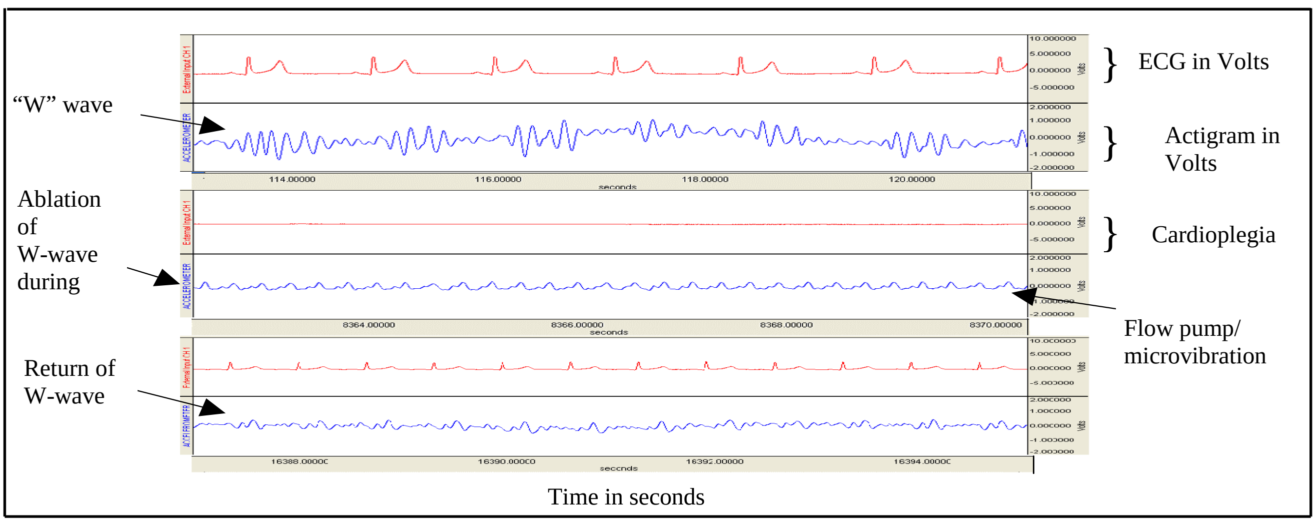

Fig 3. Electrocardiogram (upper tracings in each panel) and DSP actigram (lower tracings) in a Walter Reed patient under going cardiopulmonary bypass surgery. Upper panel shows ECG wave preceding each cardioballistic W-wave. Middle panel shows period when the patient is on a cardiac flow pump, with ablation of both ECG and actigram ballistocardiobursts. The rhythmic mechanical signature of the flow pump and low-amplitude physiological microvibration remain apparent. Lower panel shows return of ECG and actigraphic ballistocardiobursts following disconnection of bypass pump and return of systole.

clinical methods of evaluating severity of Parkinson's symptoms remain technologically demanding, logistically difficult, and impractical for long-term daily/routine use.[11]

Human neurophysiological biosignals have historically been measured by other clinical mechanisms. Electromyography (EMG), for example, provides objective monitoring of single muscle characteristics while EEG through the array of scalp-applied electrodes, can often localize the brain region responsible for seizure activities. The EEG and EMG give perhaps the most accurate and focused measure of cortical and motor activity, but are technically complex. They require specially trained physicians and technicians, expensive equipment, and are difficult to apply in ambulatory settings. The application of actigraphy may enable ambulatory monitoring of some of the physiological signals previously requiring highly technical and sometimes invasive techniques.

Clinical Utility

Should the Warfighter become a casualty, the DSP actigraph could have a variety of applications to assist with diagnosis and therapy. Clinical studies at WRAMC are currently using the DSP actigraph to evaluate whether pain has a characteristic biovibration pattern, and whether response to pain medications can be quantified through changes in biovibration patterns. Such an application would be the first objective quantification of pain, and make improved pain management possible. Protocols are approved at Walter Reed to study the actigraphic signatures of specific brain injury patterns, such as in brain trauma and in seizure disorders, and studies are proposed to model the effects of neurotoxin exposure on motor signal characteristics in patients with degenerative and benign tremor.

Tremor and seizure are examples of conditions that could potentially be detected and characterized by actigraphy. Both tremor and seizure may occur as a result of chemical agent exposures or head trauma, as a potential consequence of excessive stimulant use (such as with caffeine or amphetamines), or as a manifestation of fear and stress. Tremor may be studied most easily in a Parkinson's Disease model, where the characteristics of the tremor have been widely described, and the pathophysiology of the disease well understood.[12] Seizures are currently diagnosed by EEG. The equipment and application of EEG are expensive and difficult to apply in an ambulatory setting. If human biovibration patterns were identified for specific seizure types, wrist-worn actigraphy would offer the potential for ambulatory diagnosis of seizures at a substantially reduced cost.

The WRAMC currently has an ongoing study using actigraphy to quantify levels of unconsciousness, specifically, to distinguish sleep from coma (Figure 4). Recent data from these studies shows that sleep and coma can look very different from one another and clearly show that life-and-death can be differentiated (Figure 5). Close collaboration between WRAIR and WRAMC on these groundbreaking efforts is required for these efforts to succeed.

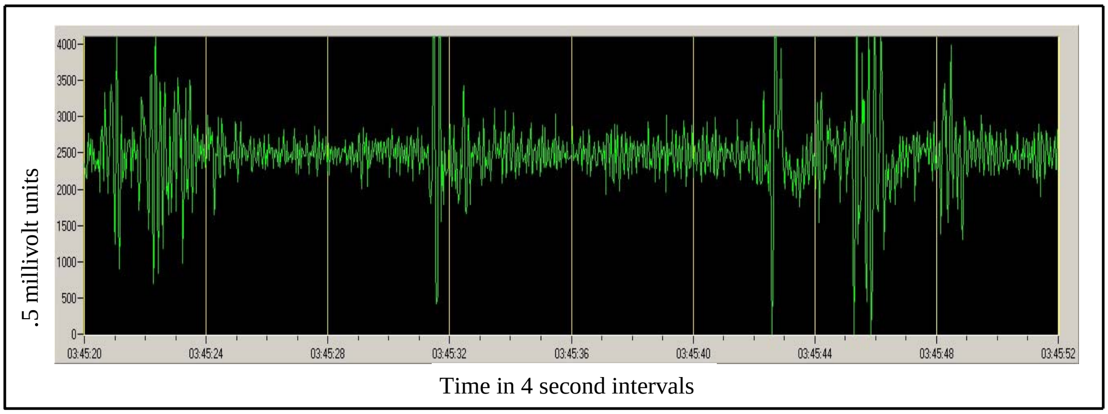

Fig 4. Patient at Walter Reed in a Glascow level 8 coma, as measured by DSP actigram over a 30 second period. Large bursts are spontaneous limb movements. Small regular-interval bursts are cardioballistic pulsations. High frequency low amplitude background activity is life signs biovibration, hypothesized to be the summation of internal systemic reverberation.

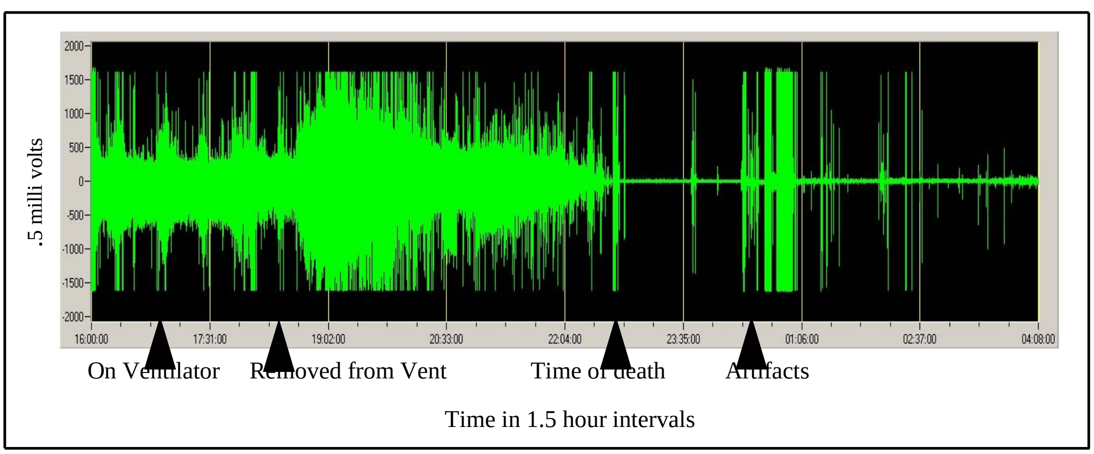

Fig 5. Advanced DSP actigram over a 12-hour period in a patient transitioning from deep coma to death. Note high-density signal prior to death, and flat line (no signal) following death. Note that following removal from ventilator, core activity increases then gradually tapers to point of cessation.

Contributions to the Warfighter and Combat Medic

The actigraph is intended to be an integral component of the Warfighter Physiological Status Monitor, with information, including sleep status, available to assist with operational planning and possibly with remote triage and casualty management. The battlefield environment is rich in vibration and movement and any projected use of a motion monitor would require algorithms to discern nonhuman vibration patterns from human motion. Algorithms would have to be developed and applied to cancel mechanical motion, such as would be generated by ground or aerial troop transport vehicles.

Vibrational motion as would be found in rotary wing platforms can elicit many of the same symptoms of sleep deprivation, and the effects of mechanical vibration on cognition would also have to be assessed when actigraphy is applied to measure alertness and predict cognitive performance potential. In 1976, Graybiel and Knepton coined the phrase "Sopite Syndrome" to define a subset of people who become tired or lethargic from motion but do not suffer from symptoms such as nausea or vomiting.[13] Graybiel and Knepton noticed a variety of other related symptoms: apathy, decreased ability to concentrate, daydreaming, melancholy, sleep disturbances, performance errors, frequent daytime napping, irritability, and a desire to be left alone. While little is known about the potential impact of the Sopite Syndrome on civil and military aviation, some evidence shows that airline cabin crews suffer from post-flight fatigue and sleeping problems more often than cockpit crews despite being less confined.[14] It was hypothesized that with exposure to fewer external visual references concerning the true direction of the plane as well as reduced continuous sensory feedback typically associated with pilots' commands on the craft, cabin aircrews were more susceptible to Sopite Syndrome.[15] As such, it is reasonable to consider that similar symptoms may develop in troops during enclosed cabin transport.

The constant pounding and reverberations of the battlefield, the rolling and bouncing movement of ground vehicles, and the high vibration of rotary-wing aircraft all produce movement that would interfere with a motion sensor's ability to detect human biovibrations. Rudimentary algorithms exist to cancel specific components of the mechanical vibration, but thus far, there is no systematic study of this problem and no algorithm to completely mitigate the mechanical noise effects. Consequently, sleep scoring is not currently reliable in moving ground, sea-based, or aerial vehicles. The question of human verses nonhuman motion, and the effects of vibration on cognition may be answered through use of the high-fidelity simulators and research UH-60 available at the U.S. Army Aeromedical Research Laboratory at Fort Rucker, AL, and in collaboration with the Naval Medical Research Laboratory in Pensacola, FL.

Actigraphy may be a viable and nonintrusive method of assessing shiver. Extreme cold weather or water immersion can lower body temperatures and adversely impact military operations by increasing the risk of cold injury and reducing physical and cognitive performance. Prediction of core body temperatures during exercise in cold water using thermo-regulatory models is based on limited data.

Many different factors have a role in body core temperature responses during cold-water immersion. These include (1) water temperature; (2) immersion depth; (3) body fat; and (4) metabolic rate. A decrease in water temperature increases the thermal gradient between the person and the environment and leads to significantly greater heat loss via convection and conduction. The greater the depth a person is immersed in water, the greater the effective body surface area for heat exchange between the person and the water, which will cause core temperature to decrease more rapidly. People with higher body fat percentages tend to lose heat less rapidly than thin people in cold water (Carlson et al).[16]

Heat production in response to hypothermia is assumed to come from an initiation of involuntary motor activity – shivering, as an attempt to prevent the reduction of core body temperature. Assessment of shiver, however, has been tenuous at best and has been heavily dependent on observations and grading of shiver on various rating scales. These scales vary in criteria, contain limited discrete values, and are often subjected to rater bias. Although more objective techniques such as EEG recordings have been used to assess shiver, these measurements are hampered by their intrusiveness and limited stationary recording intervals. Therefore, it is relatively impossible to both predict a person's temperature or their thermoregulatory response after water immersion. It is hoped that the actigraph can aid in these measurements. These questions may be answered by investigations performed in the thermal laboratories at the U.S. Army Research Institute of Environmental Medicine in Natick, MA.

Summary and Conclusions

Human body microvibrations have been identified in clinical studies and appear to be a life signs indicator. Sleep appears different from coma, and respirations and heart rate can be identified in the actigraph signal. We hypothesize that each human may even have his or her unique microvibration signature.

Actigraphy is a tool that records motion signals both physiological and mechanical in origin, but the meaning of the actigraph signal is not self-evident from the signal output. Continued research is required to collect and analyze these motion signals and develop the algorithms necessary to distinguish the militarily relevant human from mechanical signal components.

Actigraphy as a technology is mature and easily applied. Applications in militarily relevant environments are unstudied, with little research underway, and none to answer even the most basic questions of how to separate human from mechanical signals.

The wealth of information in the actigraphic signal may be exploited for both continuous physiological monitoring as well as medic or commander seeking to discern if a casualty is alive or dead. As the Future Force Warrior is likely to wear an actigraph, research should continue to discern the militarily relevant components of the actigraph signal. The questions are many and the search for answers is only just beginning.

Department of Defense (DOD) Disclaimer

Human volunteers participated in these DOD studies after giving their free and informed consent. The protocols for these study were approved by the WRAIR Human Use Review Committee. Investigators adhered to AR 70-25 on the use of volunteers in research. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the DOD. Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

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Parachutist Neck Injury Risk Associated with Head-Borne Mass

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Frederick T. Brozoski†††

Parachutists are at risk of neck injury. While helmets provide important protection, they also increase the weight supported by the neck, potentially increasing the risk of neck injury. The addition of further weight, in the form of helmet-mounted devices, may worsen the risk. We were asked to assess the injury risk presented by one such device, the Individual Combat Identification System (ICIDS). A study was conducted with an instrumented manikin to measure and record transmitted neck loads during parachute opening while wearing the ICIDS attached to the standard U.S. Army paratrooper helmet. The ICIDS was recommended for clearance for follow-on user testing by the Airborne and Special Operations Test Directorate.

Introduction

Paratroopers are exposed to unique injury risks. Some of these risks are associated with the dynamics of parachute opening shock (POS) and the parachutist's landing fall (PLF).[1,2] During POS events, the neck is a potentially vulnerable body region because the head is likely to flail as the inertial loads overcome voluntary muscular control. These head flail inertial loads are resisted by the neck bone and soft tissue structures. Prior studies of static line parachutist injuries reveal that the cervical region is not a frequently injured body region.[3-7] This suggests that inertial loads created during POS with existing helmets do not frequently exceed human tolerance. Neck loading dynamics may be altered when head supported devices are worn, adding weight to the head/neck complex. Increased risk of neck injury in the paratrooper population could have obvious long- and short-term consequences, both in terms of health and mission outcome. The objective of this study was to assess the risk of acute neck injury resulting from exposure to POS while wearing a developmental helmet mounted device.

Method

An instrumented test manikin was repeatedly exposed to parachute openings while encumbered with different head-borne mass conditions. The manikin was a Hybrid III automotive test dummy, modified with an articulated spine and internal data acquisition system. The internal data acquisition system was mounted inside a pelvis box. The spinal column was modified with two axial torsion joints and three rubber discs to increase spinal column range of motion (axial rotation, sagittal flexion and extension, and lateral bending).

Electrical power was provided to the manikin through rechargeable batteries stored in two ammo pouches located on the Load Bearing Equipment (LBE) harness system fitted to the manikin. The manikin dressed and configured with the LBE and T10 parachute is shown in Figure 1. No additional combat or field gear (weapons, ammunitions, rations, field pack, etc) were used in this study because of the increased variability it would have added to the manikin's aircraft exit. The addition of combat loads could increase the total weight by 100 to 150 pounds, depending on the particular gear selected. The manikin instrumentation is provided in Table 1.

Fig 1. The test manikin dressed and configured with the LW-V1.0 helmet, LBE and T10D parachute.

Two different head-borne mass conditions were evaluated. The standard Army infantry helmet (the Personal Armor System for Ground Troops [PASGT]) configured for airborne operations was used as the baseline. In the encumbered condition, the ICIDS was attached to the PASGT helmet. The weights and center of mass locations for these conditions are plotted in Figures 2 and 3. Helmet center of mass locations were measured relative to the head anatomical coordinate system. Contained in Figure 2 are regions identified as "acceptable" and "unacceptable." These regions were developed for the U.S. Army aviator environment and are based on biomechanical response changes of seated subjects in a vibration environment.[8,9] Figure 3 contains two regions identified as "severe neck injury risk" and "accepted injury risk." These thresholds were developed for the U.S. Army helicopter crash environment.[9] The criterion regions of Figures 2 and 3 are provided for reference in the absence of paratrooper specific head supported weight criteria, although it is recognized that the aviation crash environment is much different from the POS scenario.

Body region	Measurement	Sensitive axis
Head CM	Linear accel	X, Y, & Z
Head CM	Angular velocity	Y-axis
Upper neck (C1)	Forces	X & Y
Upper neck (C1)	Moments	X, Y, & Z
Lower neck (C7/T1)	Forces	X, Y, & Z
Lower neck (C7/T1)	Moments	X, Y, & Z
Lower neck (C7/T1)	Linear accel	X, Y, & Z
Chest (sternum)	Linear accel	X, Y, & Z
Lower lumbar (L5)	Forces	X, Y, & Z
Lower lumbar (L5)	Moments	X, Y, & Z

Table 1. Manikin Instrumentation

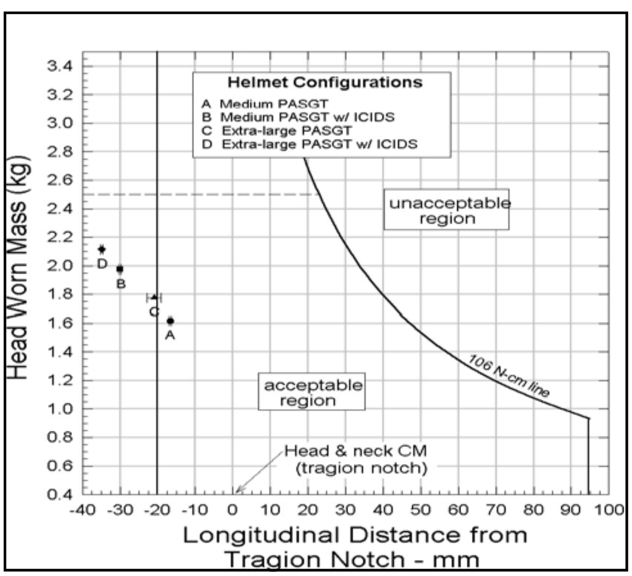

Fig 2. The test manikin dressed and configured with the LW-VI.0 helmet, LBE/T10C parachute.

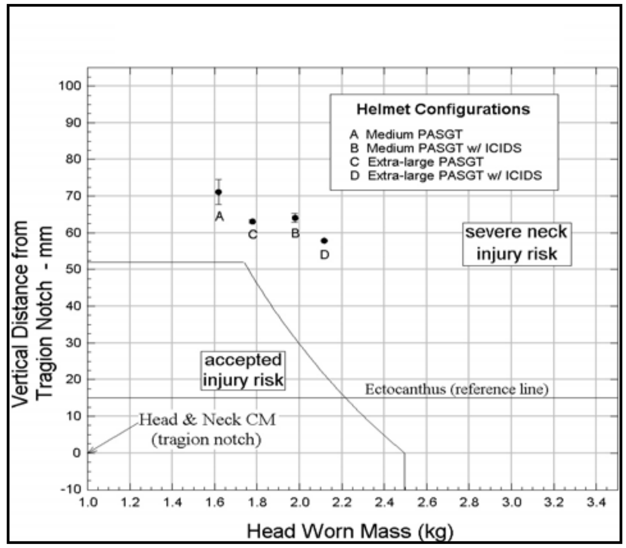

Fig 3. Test helmet mass and verticel (Z-axis) center of mass (tragion notch), plotted against the USAARL-recommended head-supported mass criteria for Army aircrew helmets.

The ICIDS and standard PASGT helmets were assessed at 110 knots indicated airspeed, using an Army JUH-60A Black Hawk helicopter. The manikin was released at 500 feet above ground level, and a standard T10 parachute (circular canopy, static line deployed) was used for all exits. A slide was fabricated and installed in the aircraft (Figure 4) to assist in obtaining a consistent manikin exit from the aircraft.

Fig 4. The JUH-60 Black Hawk helicopter with the manikin exit slide installed, oriented for a left side exit.

The data channels analyzed for this study included the upper neck forces and moments. Two data analysis methods were used. First, a one-way analysis of variance was conducted to determine if the addition of the head-mounted weights produced a statistically significant difference ($P<0.05$) in the transmitted neck loads of the study helmet to the baseline helmet. Second, the peak neck forces and moments measured at the upper neck load cell were compared to neck injury assessment reference values (IARVs) established in the Federal Motor Vehicle Safety Standard (FMVSS).[10,11] These criteria were based on the expected level of force or bending moment likely to induce level 3 injuries on the Abbreviated Injury Scale (AIS)-3. The AIS scale is an indicator of injury severity, shown in Table 2.[12] The automotive IARVs for transmitted neck forces are reproduced in Figure 5. The IARVs for neck moments are 1681 and 505 inch-pounds for flexion and extension, respectively. No reference thresholds exist for lateral bending or axial torsion. Forces and moments that are below the corresponding IARV indicate that the occurrence of injury is considered unlikely for the environment being evaluated.

AS Code	Description
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum

Table 2. The AIS Code for Injury Severity

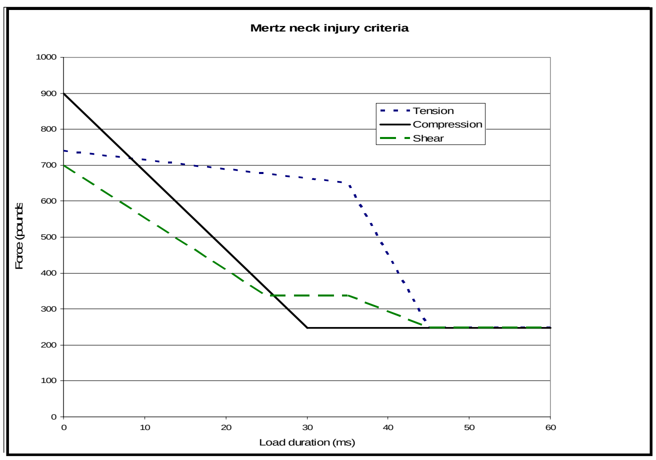

Fig 5. The injury assessment reference curves for neck tension, compression, and fore/aft shear measured at the head/neck interface of Hybrid III-type dummies. This figure was constructed by consolidating curves presented by Mertz.[11]

Results and Discussion

Use of the JUH-60 Black Hawk proved to be an efficient method to conduct multiple aircraft exits, allowing 15-minute test cycles. Seven of 34 helicopter-exit data sets were eliminated from the analysis due to signal contamination resulting from riser snag. An example of the electronic data signals from the neck upper and lower load cells is shown in Figure 6.

The peak values for the upper neck load cell moments and forces were used to calculate the mean and standard deviations (Table 3). Only neck flexion (+My) produced a significant difference ($P<0.05$) from the standard paratrooper helmet. The peak force and moment values were well below the FMVSS neck injury assessment reference values.

Neck load variable	FMVSS IARV	PASGT (n=14) mean	PASGT (n=14) SD	ICIDS (n=13) mean	ICIDS (n=13) SD	P-value
Lateral bend, +Mx	None	127.8	75.8	142.6	85.2	.64
Lateral bend, -Mx	None	-146.6	60.7	-148.6	80.2	.94
Flexion, +My	1681	104.6	51.2	184.4	123.1	.04
Extension, -My	505	-73.4	50.1	-59.7	36.1	.42
Forward sheer, +Fx	697	83.4	31.7	73.1	38.2	.45
Rearward shear, -Fx	697	-88.8	23.2	-93.7	35.7	.67
Lateral shear, +Fy	697	39.0	14.7	39.5	30.1	.95
Lateral shear, -Fy	697	-54.7	19.4	-58.2	28.1	.71
Tension, +Fz	742	179.3	88.7	177.8	81.1	.96
Compression, -Fz	900	-39.9	34.0	-52.2	29.2	.33

Note: Unites are inch-pounds for bending moments and pounds for forces.

Table 3. Comparison of Means for Peak Neck Loads During Parachute Opening.

A new set of neck injury risk curves have been proposed for tension and extension moment measurements of crash dummies.[13] Initial assessments of the peak values recorded during this test series (Table 4) against the proposed criteria reveal the risk of introducing an AIS-3 level neck injury to be below 0.1%. The inertia neck loads are not high enough compared to the injury thresholds established for physical contact loads. The FMVSS IARVs have been established for occupant safety in ground vehicle crash impacts and may be too high to detect or suggest lower severity neck injuries (for example, strain, sprain). Low severity neck injury criteria are being reviewed for potential application to the parachuting environment.

There are caveats to these conclusions. Research using human surrogates (for example, manikins) is, at best, an estimate of the true probability of injury to humans. The manikin does not bend in the same manner as a living human and has no intentional movement capability; also, these limited

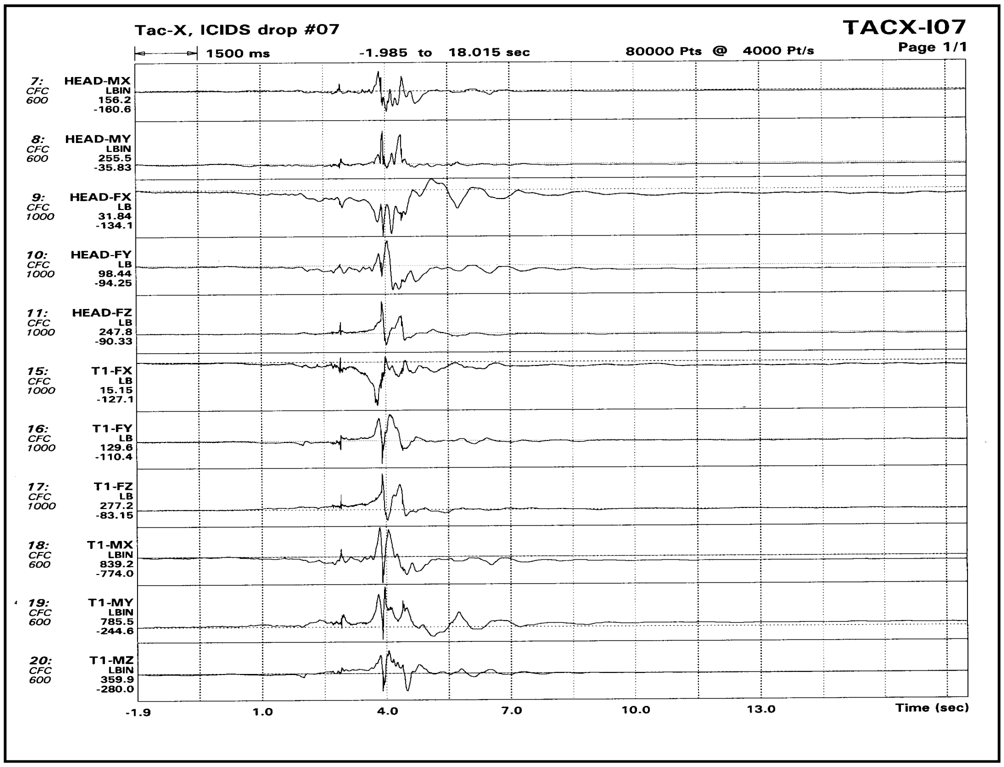

Fig 6. Electronic data sample from the neck upper and lower load cells.

Neck load variable	FMVSS IARV	PASGT (n=14) Peak	ICIDS (n=13) Peak
Lateral bend, +Mx	None	355	289
Lateral bend, -Mx	None	-332	-454
Flexion, +My	1681	299	380
Extension, -My	505	-177	-127
Forward shear, +Fx	697	118	184
Rearward shear, -Fx	697	-159	-140
Lateral shear, +Fy	697	70	102
Lateral shear, -Fy	697	-86	-94
Tension, +Fz	742	254	396
Compression, -Fz	900	-124	-106

Note: Units are inch-pounds for bending moments and pounds for forces.

Table 4. Peak Neck Loads During Parachute Opening Shock

tests do not represent all the possible exit and POS variations. Further, the selection of appropriate neck injury criteria is controversial. Unfortunately, there are no neck injury criteria that directly apply to the paratrooper scenario. The criteria used in this study are the best available, but were developed for automotive crash safety applications, which do not include the "downward" (Gz) accelerations seen in parachute opening shock. Finally, the results of the present study apply only to the acute injury risk from a single jump.

Conclusions

The ICIDS-configured helmet produced a statistically significant increase in neck flexion moment ($P<0.05$) over the standard paratrooper helmet, although the peak flexion moments remained below the published neck injury thresholds. Although there are important limitations to this methodology, the ICIDS helmet configuration is recommended for operational testing with human paratroopers.

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Human Error and Individual Failures in U.S. Army Aviation Accidents

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(This article is based on an article previously published in the November 2003 [Vol 31, No 11] issue of ***Flightfax:*** U.S. Army Safety Center, Fort Rucker, AL.)

"The human is the weakest link." This statement can often be heard when people describe accidents of any sort. Given the complexity of the machinery and computer technology that make up today's aircraft, it is mind-bending to think that humans would be the weakest link. Surely, components will break and computers will fail more than aircrew! On the other hand, could it be that machine parts and computer processes perform consistently, whereas humans are more easily affected by situations, environments, and personal factors? This is a question that plagues the field of human factors.

The Army Aviation environment is ripe for human errors due to factors such as operational tempo and the addition of advanced technology in the cockpit. For example, today's aircraft with multifunction displays (MFDs) often have increased capabilities over their traditional counterparts (e.g., map displays vs. kneeboards and paper maps). This increase in functionality may not only increase the amount of information available to aviators in the cockpit, but also increase the missions and tasks they are responsible for while in flight. The addition of functions and tasks requires pilots to spend more time managing the aircraft as opposed to flying it. Essentially, the more time pilots need to spend inside the cockpit managing the aircraft and flight systems, the less time and attention they have to direct towards keeping the aircraft in flight and away from obstacles. Increased head-down time in the cockpit can significantly impair pilots' abilities to maintain situational awareness, as well as properly coordinate their actions and that of their crew. The combination of these factors might lead to increased aircraft accidents due to human error.

Within the aviation realm, it is common to hear the statistic that 80 percent of accidents are due to human error. In fact, there are whole divisions of researchers working on these questions, trying to determine the incidence of human error, the best way to classify accidents, and how to catalog human errors in these accidents. The main reason to do this is to better learn from accidents in order to improve risk management and thus reduce the potential for future accidents.

While the Safety Center is the organization primarily responsible for accident investigations and analysis, the information gathered by their investigators is useful for many in the human factors field. Their Risk Management Information System (RMIS) Web site provides information regarding accident rates and statistics, as well as details about accident causes and recommendations. Researchers then use this information to answer some of these human factors questions.

There are several frameworks used by different organizations and researchers to evaluate accidents and their causes. Before getting to the big questions regarding human error in Army Aviation accidents, let's review a few facts about accident data. We all know that aviation accidents can be called flight, flight-related, or ground accidents (depending on their circumstances) and are classified according to their severity (class A, B, C, D, or E accidents). The accident investigators determine the causes (environment, materiel, or human error) of each accident to answer the question of *what happened*. Investigators also evaluate the system inadequacies or root causes present in each accident in order to determine *why the accident happened*. This further classification allows for a more detailed understanding of factors present in the Army Aviation environment that can hinder safe operations.

The system inadequacies or root causes considered include support, standards, training, leader, and individual failures. Each of these root causes is mapped and detailed in figure 1. Of course, many accidents have more than one causal factor and multiple root causes can be present. For our current purposes, we are interested in examining human errors more closely and also looking specifically at individual failures present in those human error accidents.

One important question in analyzing Army Aviation safety is, "How often is human error a cause of accidents?" By looking at the RMIS database for years that both traditional and MFD-equipped cockpits were flying, we see that human error definitely played a role or was suspected in 42 to 72 percent of accidents (see the accompanying table).

However, acknowledging the presence of human error is merely the first step. A more complete understanding can only be developed when looking at the root causes of these accidents.

As described in figure 1 on the next page, there are several root causes, all of which are important. Yet, the individual failure category contains failures that are most typical when thinking about human error. These failures are actions tied directly to the crewmembers. Some errors categorized as individual failures are overconfidence, complacency, crew coordination lapses, crew issues, and distraction due to high workload. While it is not possible in the space allotted here to define every possible individual failure, here are a few descriptions and examples.

		Chinook		Black Hawk		Kiowa		Apache	
		FY 90-02		FY90-02		FY85-02		FY97-02	
		No.	%	No.	%	No.	%	No.	%
	Total	101		267		385		107	
Human	**Definite**	38	38%	159	59%	263	68%	43	40%
Error	**Suspected**	4	4%	19	7%	16	4%	8	7%
Present?	**Unknown**	0	0%	10	4%	6	2%	3	3%
	No	59	58%	79	30%	100	26%	53	50%

Note: Fiscal years were chosen due to an ongoing research project of the author.

Table. Percentages of Accidents for Each Airframe due to Human Error

Overconfidence and complacency – These two attitudes often are found in similar situations. They are both tied to an individual's confidence in himself, his crew, his aircraft, or his ability to handle situations, and can result in poor decisions while in flight. Pilot confidence is a very good thing; however, in Army Aviation, the saying "You can't have too much of a good thing" is not always the case. A common example of overconfidence is continued flight in decreasing weather, which often leads to problems.

Crew coordination – Thankfully, much attention and training have been geared toward improving crew coordination. The ability of crewmembers to distribute workload while flying and accomplish their missions is dependent upon their ability to communicate effectively. Unfortunately, there are other crew issues that often are not addressed that can adversely affect a crew's coordination abilities.

Crew issues – The makeup of a pilot crew can be an important factor in crew coordination. How often have you heard of situations where a student pilot said he assumed the IP had the controls or knew what he was doing? What about times when there are experience or rank differences in the cockpit? Is it possible that student pilots and junior officers are reluctant to question their copilots' actions, thus hampering crew coordination? In fact, accident investigators have found that, oftentimes, a pilot's confidence in his IP or higher-ranking copilot can hamper communication. For example, he might refrain from providing obstacle clearance details because he thinks the other pilot's experience means he doesn't need assistance. However, what the pilots in these situations didn't know (because there had been a breakdown in communication) was that their experienced copilot was involved with other tasks and needed their input.

Distraction due to workload – Workload in aviation operations is often high, especially with the technological advancements of recent years. The susceptibility to distraction while flying is always a great risk and a major contributor to individual failures. The need to maintain attention outside the aircraft is in conflict with the time taken to manage flight tasks with attention inside the aircraft. A brief review of accident findings shows that division of attention is extremely important. For example, in one accident, the findings included statements that, "Both crewmembers were focused inside the cockpit…" and "Failure to effectively divide cockpit duties… " Another accident with a completely different flight scenario was found to be the result of "… attention diverted inside the cockpit" and "…both of the crewmembers had focused their attention inside the aircraft…" As you can see, these are very similar findings indicating improper management of workload and cockpit attention is an important and common individual failure.

These individual failure descriptions are examples of how crewmember actions and attitudes can affect human error in Army Aviation accidents. You might be wondering how commonly individual failures actually are identified in the accident database. As it turns out, when looking at the same sample of accidents discussed earlier, we see there are individual failures identified in 84 to 92 percent of accidents classified as having a human error component. Figure 2 shows the percentages for each airframe found in the Army today.

This is not to say that only individual failures are present. These numbers indicate at least one individual failure was identified by either the accident investigators or the author's research team; many of the accidents had a combination of failures, including support, standards, training, and leader failures. For example, of the 42 Chinook accidents in this sample that were due to a definite or suspected human error, 37 (88%) had at least one individual failure. The other 5 accidents

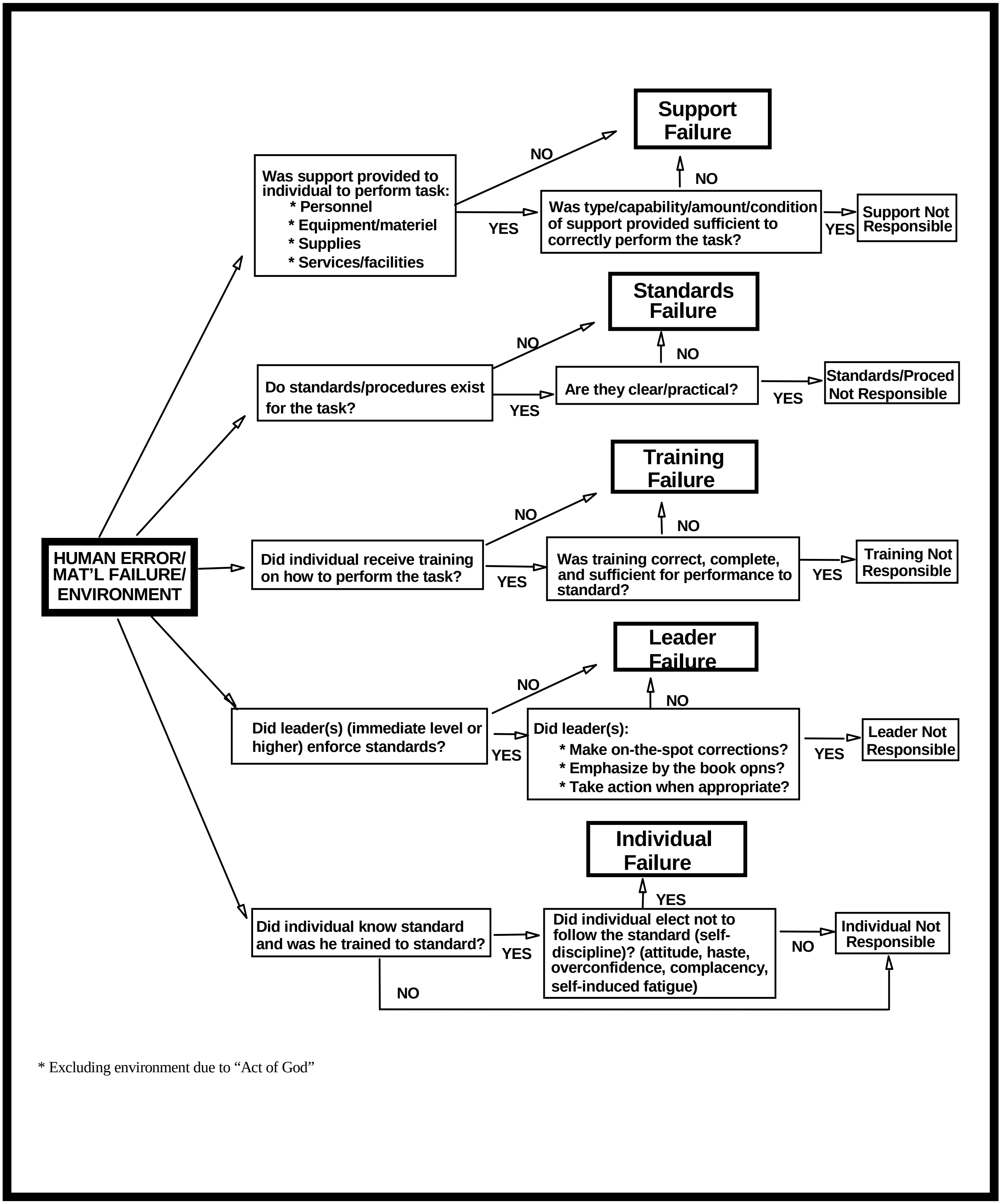

Figure 1. Determining System Inadequacy(cies)/Root Cause(s) Responsible for Accident Cause Factors (Human Error/Materiel Failure/Environment)*

(12 percent of the 42) had other failures identified, but no individual failures present.

Thus, at least within this sample of human error accidents, individual failures occurred frequently. A more detailed review of all accidents might be of interest to evaluate the prevalence of individual failures across the board. Nonetheless, it is important to remain aware of the importance of workload, crew coordination, and aircrew attitudes such as complacency and overconfidence in order to increase Army Aviation safety.

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Note: Accidents included in this chart are from the same sample as displayed in the table on page 36 due to the author's ongoing research.

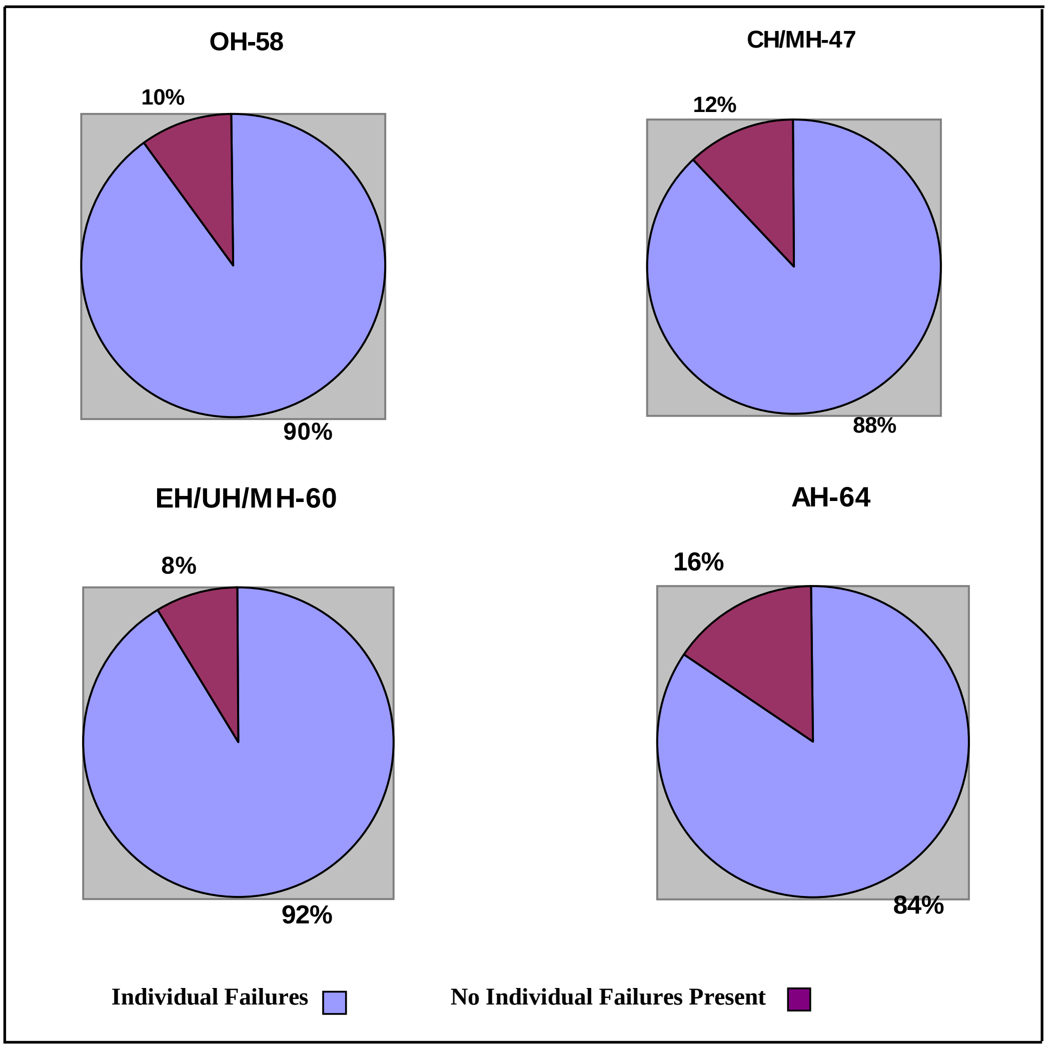

Figure 2. Percentage of accidents that had a human error cause also had at least one individual failure.

Focus on Supernormal Vision

LTC Corina VanDePol, MS, USA†

Introduction

The human visual system is capable of a much higher level of acuity than most think of as "normal vision." Assuming an individual does not have any visual conditions other than refractive error, vision is usually correctable to 20/20 Snellen acuity or better. Refractive error, which includes myopia, hyperopia, and astigmatism, does not completely define the optical properties of the eye, however. It only characterizes the simplest errors in the accuracy of the focusing system, defocus and astigmatism. These are known as the lower order aberrations (LOA) and are correctable with spectacles or contact lenses. Through the development of technologies that were initially used to measure and correct the aberrations of the earth's atmosphere and later configured to measure the optics of the human eye, we are now able to more completely define the eye's optical imperfections that cause reductions in image quality on the retina. Measurement will eventually lead to technologies to correct these more complicated imperfections, known as higher order aberrations (HOA). The primary question is whether correction of HOA beyond the LOA will result in significant improvements in human visual capability. Challenges to researchers and developers include determining the limits of the human visual system, identifying the optimal correction and then achieving a means to deliver the correction in a nonobtrusive, operationally useful way.

Beyond the focusing mechanism of the eye, the human visual system has other components which impact the ultimate level of visual capability. Particles within the focusing components of the eye, the cornea and lens, and the optical media itself, aqueous and vitreous humors, scatter a percentage of the incident light and reduce image quality. The pupil acts as an aperture to limit the amount of light entering the eye. At its smallest size, approximately 2 millimeters in diameter, the pupil limits the image forming properties of the eye at the diffraction limit. As the pupil increases, image quality generally decreases, despite the increased amount of light entering the eye.[1-3] This is due to the increasing impact of optical aberrations of the eye. The photoreceptor mosaic or spacing of the receptors on the retina is perhaps the greatest limitation in potential visual acuity. Photoreceptors are most dense in the fovea of the retina. Photoreceptors discretely sample the image. In order to see two points as separate points, two stimulated receptors have to be separated by at least one unstimulated receptor. If the optics of the eye spread the image over the center receptor, it will be stimulated as well and the eye will not be able to resolve the space.

Using an estimated normal cone density of 158,000 per square millimeter in the fovea, the cone spacing is 2.5 microns from center to center which equates to 0.5 minute of arc. Normal visual acuity of 20/20 Snellen occurs when a spacing in the object of 1 minute of arc is resolvable. When the optical aberrations of the eye are corrected, increasing pupil size leads to improved optical quality, as opposed to decreased optical quality, and the density of the photoreceptor mosaic then remains as the limit of the visual system. Therefore, it is estimated that the best visual acuity possible is 20/10 or better, depending on individual receptor spacing. Some estimate that an acuity of 20/8 or 20/5 may be attainable.[4-7] The neural limits of the post-receptor retina and brain must be taken into consideration as well, since true "vision" occurs in the visual cortex. Research has shown that the neural limit for resolution is at least that of the retinal receptors.[8] Therefore, of all the limits to image quality of the eye, correction of the optics, and specifically the HOA, has the greatest potential for improving vision to the level of "supernormal vision." This article provides a review of aberrations of the human eye, techniques for measurement of the eye's optical aberrations, methods for correcting HOA, and obstacles to overcome for achieving useable supernormal vision for military applications.

Aberrations of the Eye

Light coming from a distant point of light arrives at the eye as a plane or flat wave. The light is then bent by the optical elements of the eye and focused onto the retina. In an eye with a perfect optical system, the flat waves would be bent or refracted equally and the image formed on the retina would be a point of light identical to the object point of light. Any deviation from perfect optics is referred to as an aberration. The most prominent aberrations of a normal eye are defocus and astigmatism, the LOA. Defocus is an overall or global excess or deficiency in focusing power of the eye. This aberration is easily corrected by providing a spherical lens that either decreases or increases the vergence of the entering light wave. Astigmatism is a difference in focusing power between two meridians of the eye, generally due to the cornea having a more powerful curvature vertically than horizontally. Although the orientation of the astigmatism cross may be in any position, the meridians are always 90 degrees apart in regular astigmatism. This aberration is also correctable by a lens, in this case a cylindrical lens with power elements 90 degrees apart corresponding to the orientation and amount of astigmatism error of the eye.

The HOAs are the aberrations that remain after correction of the LOA of the eye. Figure 1 shows the aberration structure of normal and post-refractive surgery eyes of Army flight school applicants. Note that LOA are predominant for both groups. The primary differences are in the HOA, specifically coma and spherical aberration. The HOAs cause more subtle distortions in image quality and, until very recently, were not a consideration when prescribing optical corrections for the human eye. In fact, before the advent of refractive surgery, very few individuals experienced the effects of HOAs, except those with corneal conditions such as keratoconus, pellucid marginal degeneration, transplant or injury. The effects experienced by post-refractive surgery patients have been described as halos around lights or glare and other disturbances of quality of vision, especially noticeable at night when the pupil of the eye is large and the impact of distortions in the corneal optics is more pronounced. As these complaints increased, more attention was paid to the HOA created by refractive surgery in the wake of only correcting the LOA with conventional laser protocols. In a way, the quest for correction of LOA with alternatives to spectacles and contact lenses has directly led to technology that more accurately measures the eye and eventually may lead to technology that will accurately correct the HOA of the eye.

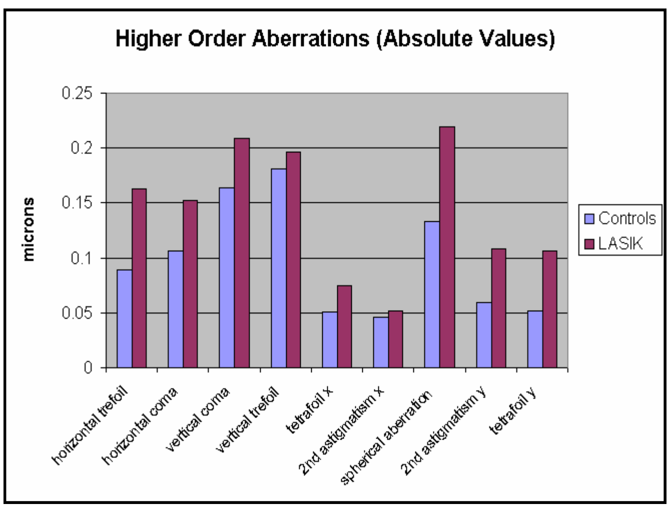

Fig 1. 3d and 4th order HOA for the right eyes of flight applicants who have not had refractive surgery (Controls; n=35) and who have had refractive surgery (LASIK; n=71). The absolute values of HOA are greater for LASIK for all measured aberrations. All differences were statistically significant at P<0.05 except vertical trefoil and secondary astigmatism at the x-axis.

Measurement of Ocular Aberrations

There are a number of technologies available to measure the aberrations of the human eye. The earliest systems were the Tscherning aberroscope and the crossed cylinder aberroscope, which both require the subject to describe or draw the distortions seen in a grid pattern. These were then interpreted as aberrations based on the specific distortions described. Further calculations were possible through evaluation of the offsets of the described grid locations from the known grid locations. The spatially resolved refractometer (SRR) uses a technique where a reference beam and an off-center beam are placed into the eye and the subject aligns the off-center beam to correspond to the reference beam. This process is repeated for a number of positions within the pupil and the resulting set of offsets can be used to reconstruct the aberration structure or wavefront of the subject's eye. Newer SRRs determine the wavefront aberration map automatically without subject settings. The Hartmann-Schack aberrometer uses the techniques developed for measurement of atmospheric aberrations in astronomy. A bright spot of light is focused on the retina, usually using a laser, which then serves as the light source for the measurement. The light emerging from the eye from the point source of light is focused onto a charge-coupled device (CCD) camera using a lenslet grid. The lenslets serve to focus each portion of the emerging wave front corresponding to its position in front of the eye's pupil. The CCD camera receives the grid of spots and these are compared to a grid of spots that would result if the eye had no aberrations (see Figure 2). The offset of each spot from the unaberrated location is used to calculate the slope of the eye's wavefront at each point. This information is then used to reconstruct the wavefront of the eye. The difference between this wave front and a planar wavefront gives the aberration structure of the eye.

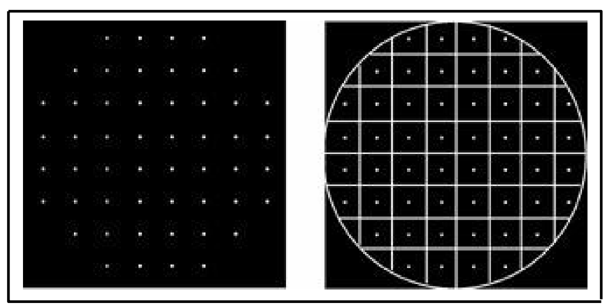

Fig 2. The array of spots captured by the CCD camera. The location of each spot within the grid shown on the right is compared to the exact center of each grid square. The offsets are used to calculate the slope of the wavefront at each point and reconstruct the wavefront error of the eye.

The measured wavefront of the eye is a surface which can be defined by an equation. The most common method involves the use of Zernike polynomials which use a circular reference base.[9] From the standpoint of interpretation, Zernike polynomials allow the clinician, or researcher, to key in on specific types of aberrations known to be more detrimental to vision quality. The lower order Zernike polynomials refer to tilt, piston, defocus, and astigmatism and encompass only the 1st and 2d orders. These, specifically defocus and astigmatism, are the aberrations correctable by standard spectacles or contact lenses. The 3d order aberrations are commonly known as coma and trefoil and are responsible for visual distortions such as "tails" on lights. The 4th order aberrations include secondary astigmatism and spherical aberration and are responsible for distortions that include "halos" around lights, primarily from the spherical aberration component. As the order increases, the aberrations are generally less significant in normal eyes, however, they may play a more significant role in post-refractive surgery eyes, as shown in Figure 1. While it is possible to calculate the Zernike polynomials to just about any order, most researchers agree that the potential impact on vision beyond the 6th order is minimal.

Correcting Ocular Aberrations

Adaptive optics technology has been successfully used to correct the aberrations of the eye and image the retina to a much finer degree than previously possible. The aberrations are measured using one of the technologies described above and the information is fed into a microelectromechanical system that applies a counter wave to a deformable mirror in the optical path of the camera and the eye. The result is an aberration free view of the retina and individual photoreceptors are now visible. An aberration free view into the eye should equate to the same view out of the eye, and studies with adaptive optics corrections have shown that high contrast acuity and contrast sensitivity do improve. Adaptive optics systems are generally optical bench or instrument-based, which in their current configuration make them less viable options for a wearable correction. The challenge, therefore, is to determine which aberrations should be corrected and how to apply the correction to the human eye.

Correcting all the measurable aberrations would probably yield the maximum possible vision, however, many of the aberrations are extremely slight and the technological expenditure needed to correct them will most likely not pay off in significant visual improvement. Instead, the impact of individual and combined aberrations should be evaluated to determine the best solution, correcting the least number of aberrations to achieve supernormal vision. Some potential modes of correction include customized spectacles, rigid contact lenses, customized contact lenses, wave front-guided corneal refractive surgery, ocular implants, miniaturized adaptive optics, or perhaps bypassing the optics of the eye altogether.

Obstacles to Achieving Useable Supernormal Vision

The aberrations of the eye change dramatically with accommodative state or pupil size. As the eye accommodates, the crystalline lens bulges and shifts forward, increasing not only the overall power of the eye, but the magnitude of many of the eye's HOA.[10-12] As the pupil of the eye dilates, the most common change in aberrations is an increase in coma and spherical aberration. This effect is much more pronounced in post-refractive surgery patients. Aberrations change with age as well (Brunette, Bueno et al).[13] It is not uncommon for people to get new spectacles every few years, especially during their teens and early twenties. The need for a new prescription is due to changes in LOA with age and is most likely accompanied by changes in HOA, which have not been considered in the past. A correction that takes low-level fluctuations and changes in aberrations with time into account either needs to constantly monitor and update the correction, as is done with adaptive optics for retinal imaging, or it must provide a fixed correction that covers a range of aberrations. As is the case with the correction of LOA, when the eye has changed sufficiently for the correction to no longer be effective, the patient will generally get an eye exam to update the prescription. The same would be true with the fixed correction option listed above.

In order to provide the maximum visual correction benefit for reduction of HOA, the correction should remain centered in front of the eye's entrance pupil. That becomes difficult as the eye moves behind the correction or the correction moves in front of the eye. The challenge is to determine how fixed this relationship has to be and how much movement or rotation of the correction can be tolerated by the visual system before maximum visual performance starts to decline.

Once an optimum correction has been established, whether it is dynamic or static, a method to provide that correction to the human eye has to be established. For military purposes, this correction needs to be as unobtrusive as possible, perhaps built into a head-mounted system or placed directly onto or into the human eye. The system will have to be able to withstand the full range of operational conditions, from vibration to environmental and luminance conditions, as well as be adaptable to various military configurations.

Summary

The human eye has the potential for greatly improved visual performance. Being able to see beyond 20/20 should greatly improve target detection and especially target recognition at a substantially greater range, certainly if vision can be improved to 20/8 or better. While telescopes and other sighting devices provide improved range of detection, these systems magnify the image and reduce the field of view. A supernormal visual correction would provide normal magnification, with a normal field of view and enhanced acuity. Achieving the ideal correction to attain supernormal vision is not without its challenges, however. A concentrated research effort is needed to determine the limits of the human visual system, determine the performance impact of such a supernormal visual system, establish the ideal correction, and develop the optimal delivery system. Normal fluctuations in the aberration structure of the human eye and changes with aging need to be taken into consideration. As has been seen with refractive surgery results and even in prescribed spectacles or contact lenses, correcting vision at one point in time does not provide a lifetime correction. The eyes change and we need to be able to provide a flexible, reliable correction in order to obtain and maintain supernormal vision.

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Human Factors in U.S. Army Unmanned Aerial Vehicle Accidents

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To date there have been few, if any, studies investigating the role of human causal factors associated with Army Unmanned aerial vehicle (UAV) accidents. The purpose of this article was to examine and quantify the possible role of human error in UAV accidents. All UAV accidents for fiscal years 1995-2003 were reviewed. No single human causal factor was responsible for all accidents. However, both methods of analysis identified individual unsafe acts as the most common human-related causal factor. Our proposed association between the different major, causal factor categories shows an almost total agreement for the proportions of accidents across the Human Factors Analysis and Classification System (HFACS) and DA PAM 385-40 categories. In demonstrating that human error plays as significant a role in UAV accidents, and by identifying the type and prevalence rate of these errors, this study shows the need for emphasis on developing and implementing countermeasures that target human decision making error.

Introduction

Unmanned aerial vehicles are autonomous or remotely piloted aircraft platforms that carry various payloads (For example, cameras, sensors, communications equipment, munitions, etc). The expanded use of UAVs in Afghanistan and Iraq has brought them into the public spotlight and advocates for UAVs cite a number of distinct advantages over manned aircraft. These advantages include reducing or eliminating human loss; lowering initial system development cost; lowering replacement cost; lowering operator training investment; expanding mission time; reducing detection signature and vulnerability; being able to operate in nuclear, chemical and/or biological environments; and reducing peacetime support and maintenance costs.[1]

While UAVs offer multiple advantages, they do have some disadvantages. Many are low flying and have slow ground speeds, making them easy targets for enemy ground forces. Remotely piloted UAVs require acomplex and highly reliable communication link to the control station. Remote operators must make decisions and control inputs based on sometimes-limited sensor information, and this information has a built-in signal delay.[2] While automating some functions within a UAV control system may overcome certain remote operation disadvantages, removing the man from the cockpit reduces the ability to make rapid decisions with the maximum situational awareness. In general, computers are best at calculations and humans are best at decision-making.[3]

The U.S. Army currently fields two major UAV systems (see Figure 1): the RQ-7 Shadow and the RQ-5 Hunter. The Shadow (model 200) is a small (9 feet in length), lightweight (330 pounds), short-range surveillance UAV that is used by ground commanders for day/night reconnaissance, surveillance, target acquisition, and battle damage assessment. Capable of

Fig 1. Photographs of U.S. Army UAVs, the Shadow 200 (left) and the Humter (right).

operating at altitudes of 14,000 feet, the Shadow can carry instrument payloads of up to 60 pounds. The Hunter is a twin-engine, short-range, tactical UAV providing capability for an increased payload (200 pounds) and endurance period (up to 12 hours). It weighs 1600 pounds and has a 29-foot wingspan.[4] While having been under development and having seen limited use for several decades, UAVs are finally and rapidly coming into their own as major tactical and strategic systems on the modern battlefield.

Naturally, the increase in UAV use has been accompanied by an increased frequency of accidents. Regardless of the type of platform (for example, helicopter, tank, UAV), the Army identifies three major causes of accidents: Human, materiel, and environmental factors. Causal factors related to human error are the most frequently cited in accidents. Studies have implicated human error in accidents across virtually all occupations, with 70% to 80% involvement for civil and military aviation.[5-8] To date there have been few, if any, studies investigating the role of human causal factors associated with Army UAV accidents. The purpose of this study was to examine and quantify the possible role of human error in UAV accidents. As mechanical failures decrease with the maturation of UAV technology, human error will naturally account for a higher percent of accidents. Knowledge of these human-related causal factors is necessary for the successful formulation of countermeasures that prevent these types of accidents.

Methods

The accident data used in this article were obtained from the U.S. Army Risk Management Information System (RMIS) maintained by the U.S. Army Safety Center, Fort Rucker, AL. Data from RMIS can be retrieved by vehicle type. This search selected data only from those accidents involving UAVs. Each accident was reviewed and classified using two approaches. The first was a variant on a methodology referred to as the HFACS. The HFACS captures data for four levels of human-related failure: Unsafe acts, preconditions for unsafe acts, unsafe supervisor, and organizational influences. The four levels of human-related failure are expanded into 17 causal categories.[8,9]

The second analysis approach was based on the accident methodology defined in Department of the Army Pamphlet 385-40, "Army accident investigation and reporting." The Army uses a "4-W" approach to accident analysis that addresses the sequence of events leading to the accident. The "4-Ws" are: (1) When did error/failure/environment factor/injury occur? (2) What happened? (3) Why did it happen? and (4) What should be done about it? Human causal factors are identified during this analysis and broken down into five types of failure: Individual failure, leader failure, training failure, support failure, and standards failure.[10]

Results

HFACS Analysis.

A search for the period FY95-FY03 found a total of 56 UAV accidents. The application of the HFACS analysis approach identified 18 of the 56 UAV accidents (32%) as involving human error, either as the sole causal factor or as one of a combination of contributing causal factors. Table 1 presents the breakdown of these 18 accidents by HFACS causal factor categories. Based on all 56 accidents, the most represented HFACS category was "Unsafe acts" (20%). The second most prevalent HFACS category was "Unsafe supervision" (16%).

When just the 18 accidents involving human error were considered, "Unsafe acts" was present in 61%, and "Unsafe supervision" was present in 50% of these accidents. "Organizational influences" and "Preconditions for unsafe acts" were present in 44% and 6% of the human error accidents, respectively.

Within the major HFACS category of "Unsafe acts," four subcategories were identified: Skilled-based errors, decision errors, perceptual errors, and violations. The most common unsafe act was decision errors, present in 11% of all accidents and 33% of all human error accidents. Incidents of decision errors included: (1) when the external pilot hurried turns using steep angles of bank, preventing a proper climb rate, which resulted in a crash and (2) when the wrong response to an emergency situation was made by commanding idle power after the arresting hook had already caught on the arresting cable.

The single accident categorized as "Preconditions for unsafe acts" was further identified as a crew resource management issue. The accident report stated that poor coordination between student and instructor was present. Three subcategories were identified under "Unsafe supervision:" Inadequate supervision, failed to correct a known problem, and supervisory violations. The most common "Unsafe supervision" subcategory was inadequate supervision, present in 11% of all accidents and 33% of human error accidents. All of the accidents identified under "Organizational influences" fell under one subcategory: Organizational process. Incidents under this subcategory included: (1) failure to maintain training records and (2) lack of written guidance on inspection and replacement criteria.

DA PAM 385-40 Analysis.

The second analysis approach applied to the UAV accidents was that defined in Department of the Army Pamphlet 385-40, which characterizes accidents by five categories of failures: Individual, leader, training, support, and standards. The

HFACS category	Frequency of occurrences	Accidents	Percentage* Based on all 56 accidents	Percentage* Based on 18 Human error accidents
Unsafe acts	16	11	20	61
Skill-based errors	4	4	7	22
Decision errors	6	6	11	33
Perceptual errors	3	3	5	17
Violations	3	2	4	11
Preconditions for unsafe acts	1	1	2	6
Crew resource management	1	1	2	6
Unsafe supervision	11	9	16	50
Inadequate supervision	6	6	11	33
Failed to correct known problem	3	3	5	17
Supervisory violations	2	2	4	11
Organizational influences	8	8	14	44
Organizational process	8	8	14	44

*Note that the percentages may not add up to 100% because accidents are typically associated with more than one causal factor.

Table 1. UAV Accidents Associated with each HFACS Causal Category

application of the Army analysis identified 18 out the 56 UAV accidents (32%) as involving human error, the same accidents identified by the HFACS analysis.

Table 2 presents the breakdown of these 18 accidents by DA Pam 385-40 causal factor categories. Based on 56 accidents, the most represented Army failure was "Individual failure" (20%). The second most prevalent failure category was "Standards failure" (14%). When just the 18 accidents involving human error are considered, "Individual failure" was present in 61%, and "Standards failure" was present in 44% of these accidents. "Leader failure," "Training failure," and "Support failure" were present in 33%, 22%, and 6% of the human error accidents, respectively.

Incidents of "Individual failure" included: (1) operator misjudged wind conditions during landing and (2) crew members overlooked improperly set switch on control box. Incidents of "Leader failure" included: (1) a crewmember who did not have a current certification of qualification was assigned

Army category	Frequency of occurrence	accidents	Percentage* Based on all 56 accidents	Percentage* Based on 18 human error accidents
Individual failure	11	10	20	61
Leader failure	6	6	11	33
Training failure	4	4	7	22
Support failure	1	1	2	6
Standards failure	8	8	14	44

*Note that the percentages may not add up to 100% because accidents are typically associated with more than one causal factor.

Table 2. UAV Accidents Associated with each Army Causal Category

as an instructor pilot and (2) leadership failed to provide oversight of placing UAV in tent and having tent properly secured. Incidents of "Training failure" included: (1) training was not provided to the UAV operator on effects of wind and (2) training was not provided on single engine failure emergency procedures. There was only one incident of "Support failure," which was that a contractor did not take appropriate maintenance actions even though information was available. Incidents of "Standards failure" included: (1) written checklist procedures for control transfers were not established in the technical manual and (2) there was no written guidance on inspection and replacement criteria for the clutch assembly.

Discussion

The predominant means of investigating the causal role of human error in all accidents remains the analysis of post-accident data.[8-10] Our data are in agreement with others who have used similar analyses procedures on accident data from aviation environments. This study has demonstrated that human error does play a major role in U.S. Army UAV accidents. For the period FY95-FY03, human error was present in approximately one-third (32%) of all UAV accidents. While no single factor was responsible for all accidents, both methods of analysis categories (HFACS and DA PAM 385-40) identify individual unsafe acts or failures as the most common human-related causal factor category (present in approximately 61% of the 18 human error related accidents).

Both analyses identified the same 18 accidents involving human error. While there was no one-to-one correspondence between the categories defined by the two analyses, the authors propose an association depicted by the relationships in Figure 2. The proposed relationships loosely correlate the HFACS categories of "Unsafe acts" and "Preconditions for unsafe acts" with "Individual failure," and "Unsafe supervision" correlated with "Leader failure" and "Training failure," and "Organizational influences" correlated with "Support failure" and "Standards failure." When accidents were grouped according to the proposed relationships of causal factor categories (Table 3), they were approximately equal. Considering the small number of accidents involved, this finding would seem to strongly support the proposed association of causal categories in Figure 2.

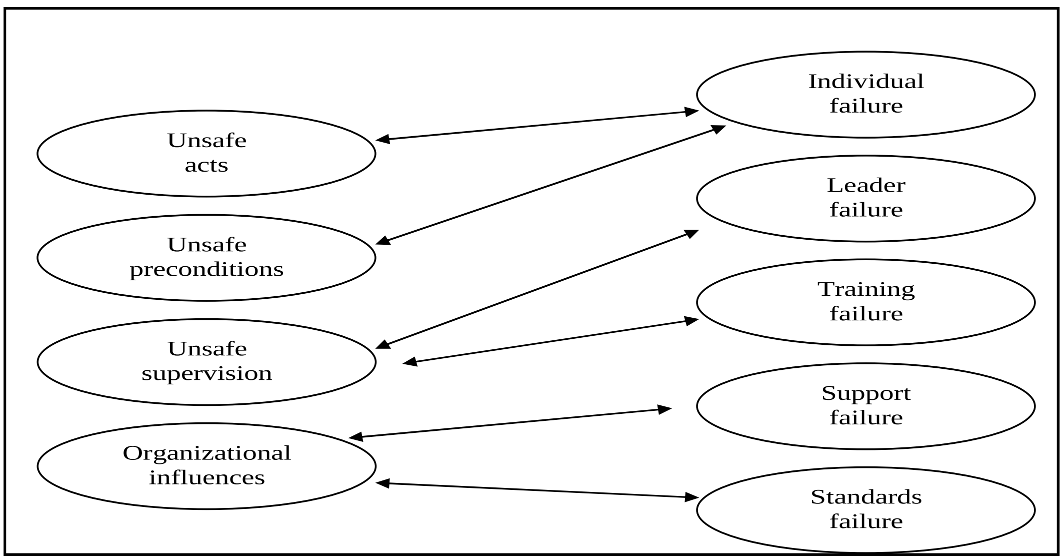

Fig 2. Suggested relationships between the HFACS and DA PAM 385-40 categories.

HFACS categories	*Sum of FACS	*Sum of PAM 385-40	PAM 385-40 categories
Unsafe acts Preconditions for unsafe acts	61%	55%	Individual failure
Unsafe supervision	50%	44%	Leader failure Training failure
Organizational influences	44%	44%	Support failure Standards failure

*Percentages exceed 100% because any given accident may have multiple causal factors.

Table 3. Accident propositions by Grouped Relationships

The proposed association between the different major causal factor categories (Figure 2) shows an almost total agreement for the proportions of accidents across the HFACS and DA PAM 385-40 categories. However, the HFACS method provides significantly greater detail in the types of human error present in the accidents. Because of this greater definition, HFACS helps identify more specific types of human error. For example, while in agreement with the Army's proportion of accidents involving "Individual failure," the HFACS analysis further separates the comparable "Unsafe acts" category into four subcategories: Skill-based errors, decision errors, perceptual errors, and violations. Decision error is identified as the most frequent individual act or failure, present in 6 of the 11 accidents under the "Unsafe acts" category.

Conclusions

The results from this study indicate that human error plays as significant a role in UAV accidents as in virtually all types of accidents. These findings suggest that there is a need to further develop and refine UAV training and safety programs that target individual mistakes. A post-accident data analysis such as this can provide a starting point for the design, examination, and adoption of appropriate countermeasures.

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Enhanced Blast Weapons and Forward Medical Treatment

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Background

Recent technological advances in explosives and materials processing have stimulated the development of "enhanced blast weapons" (EBWs). While conventional weapons rely on high explosive (HE) to drive projectiles, fragments, or shape charges to damage or destroy targets, EBWs rely primarily on blast and secondarily on heat for their effects. Confined spaces intensify the blast effects by reflection of the pressure waves from interior surfaces. They are designed to kill personnel or damage unhardened material over a wide area, including within field fortifications and behind conventional cover. EBW made their début in World War II. The German Nebelwerfer and the Soviet-made Katyusha were the first EBW. The Soviets were the primary developer of EBWs technology. This class of weapons has proliferated to numerous countries around the world. Their most recent use was in Afghanistan (by the Soviets), Bosnia (by the Serbians), and Chechnya (by the Russians and Chechens). The EBWs have become a significant medical threat to U.S. forces. To counter this threat, medical personnel must be aware of EBWs capabilities, wounding patterns, and their medical treatment. This article covers the weapon effects and the first aid and early treatment of EBWs.

Weapon Effects

While they can have effect on troops in the open, EBWs are most effective when detonated in confined spaces such as buildings, caves, bunkers, and vehicles. Whether they are employed as missiles, rockets or bombs, their effects on the target are the same. Their casualty-producing mechanism is primarily blast (overpressure) and secondary thermal effects. Blast is a rapid movement of air away from a center of outward pressure generated by an explosion that creates an overpressure or crushing effect. Confined spaces intensify the effects of the blast primarily from reflection of the pressure waves from interior surfaces. The high pressures (lower than an HE detonation) that characterize an enhanced blast explosive event are maintained for a longer duration than an explosion associated with conventional HE (See figure).

Heat is primarily a flash of energy released from the detonation of an explosive and the subsequent ignition of a fuel in the ambient air. Materials that absorb energy or effectively block paths can reduce the lethality of these blast and heat effects.

The types of injuries normally associated with EBWs are blast, burn, toxic, and psychological. The blast (overpressure) effects of EBWs are the primary lethal mechanism. The blast injuries can be divided into primary, secondary, tertiary, and oxygen depletion effects.

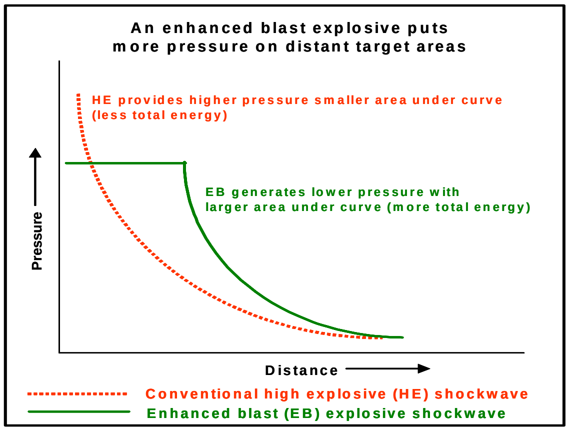

Fig. Comparison of conventional explosives and enhanced explosives.

Primary blast injuries result from the compressive effects of the shock waves transmitted to the human body. This compression results in a crushing effect that can be damaging to all soft body parts and organs. Organs that contain air, such as the lungs and ears, are the most sensitive to primary blast overpressure effects. The lungs are most vulnerable to blast overpressure and may be the greatest contributor to mortality. Internal organs such as the intestines, heart, liver, and kidney are also susceptible to damage from primary blast. The most likely result will be crushing or rupture of the organ which can lead to rapid loss of blood, the build-up of body fluids, or eventual peritonitis (infection in the abdominal cavity). Air embolisms can also occur in coronary and cerebral blood vessels.

Secondary blast injuries result from the impact of the limited fragmentation of the warhead itself and from debris displaced by the blast. In an open space, this effect will be limited. In enclosed spaces such as buildings, debris is usually present, thus increasing the potential for this type of injury. Typical secondary blast injuries are punctures or perforations of the body, bone fractures, fragment injuries to the eyes (from dirt and dust that is loosened by the blast and from unreacted metal particles from the warhead mix), and lacerations of the skin. Unless a vital organ is damaged, rapid blood loss is the primary danger of this type of injury.

Tertiary blast injuries result from the blast projecting the individual within the confined space. Typical injuries are blunt trauma, fractured bones, and amputated limbs. Again, rapid blood loss is a major danger.

The active elements in an EBW are an explosive and a fuel. These devices use the oxygen in the air as a reactant for the combustion of the warhead fuel element. A vacuum or oxygen depletion effect is prevalent. Suffocation and/or ruptured lungs are a concern with this type injury.

The heat output of an EBW is significantly higher than that of conventional HE warheads. Therefore, burn injuries are a concern. These burn injuries are primarily a result of warhead fuel-induced flash fires or flames generated by secondary fires started by the warhead detonation. At detonation, an amount of thermal energy is briefly released in the form of a high temperature flash. This form of thermal energy can cause burns that primarily affect exposed skin such as the face, hands, and arms. It also can affect the lungs in the form of inhalation burns and the eyes in the form of temporary or permanent blindness. Tests indicate that most flash induced burns (up to second degree burns) may occur in the blast room; secondary rooms do not experience a measurable threat of burns. Another result of detonation is a slower release of thermal energy in the form of flame. This energy release can easily ignite any combustible material in the vicinity of the blast. The resultant secondary fires can cause burns to skin and tissue and can generate conditions leading to smoke inhalation injuries. Inhalation of enhanced blast combustion products may contribute to internal pulmonary injuries. Some EBW warhead materials are toxic. For example, the Russian RPO-A uses isopropyl nitrate as an energetic material in the warhead. Isopropyl nitrate is a carcinogen. Care must be taken to avoid breathing the fumes and gases generated by the detonation of these warheads. Isopropyl nitrate is a colorless liquid. The Russians may have dyed it pink for ease of identification. A pink fluid or residue may be present when an RPO-A warhead malfunctions. Avoid contact with this pink fluid.

The EBWs are a class of weapons with warheads comprised of several closely related, but technically different lethal mechanisms and effects. Enhanced-blast explosives are mixtures that deliver more energy on target than traditional explosives. There are four types of recognized enhanced-blast explosives: (1) Metallized Explosives. (2) Reactive Surround. (3) Fuel-Air. (4) Thermobaric. A detailed discussion of these weapon types is beyond the scope of this article. The bibliography at the end of the article provide further information.

The EBWs, such as fuel air explosives, generate a more uniform and protracted overpressure throughout the area covered by the cloud of dispersed fuel. They are very effective anti-personnel weapons since the blast will diffract around corners. The fireball from these weapons lasts longer than the equivalent amount of HE, increasing the burn threat from flame contact and thermal radiation. In particular, these weapons create casualties by causing overpressure injuries to the lungs and other internal organs. Another major casualty mechanism is the blunt trauma resulting from collapse of a building or structure caused by the EBW. The EBWs are designed to kill or injure by primary blast effect.

The EBWs primarily kill by causing massive damage to the lungs and other internal organs. The primary kill and incapacitation mechanism is internal crushing injuries caused by pulsed blast pressures. The relatively long pulse, high-pressure waves rupture air-filled organs such as the lungs, intestines, heart, or other vital organs. Incendiary or thermal effects are a secondary source of injury. Helmets and ballistic armor may provide only marginal protection or may worsen the effects of EBWs. Existing helmets and body armor were designed to protect against bullets, fragmentation, and blunt trauma injuries. These devices help reduce the effects of secondary and tertiary blast injuries. Some foreign studies have suggested that some types of body armor may intensify blast effects. Studies by the U.S. Army Soldier Systems Command (Natick) indicated that the existing Interceptor Body armor in use by U.S. forces does not enhance the blast effect. The testing further indicates that when the ceramic plates are included, the primary blast (crushing) effects may be reduced behind the plate-protected portion of the body. The use of helmets and body armor provides protection against a wide variety of warheads and other combat trauma.

Thermobaric detonations will create three “zones” of injury. The first is the central zone where most will die immediately from blast overpressure and thermal injuries. Casualties in the second zone will survive the initial blast and burns, but will have extensive burns and those internal injuries listed above. From a medical standpoint, some second zone casualties might be able to be saved with extensive care and sufficient resources, but, in reality, between the resources required and the low salvage rate, little can be done beyond providing morphine and other pain relief. In the third zone, patients will have had some protection from flying debris, but may have experienced some blast effect. Kevlar armor may protect Soldiers from lethal missile injuries, but not from the blast effect. Surprisingly, many of the patients with internal injuries will survive and do reasonably well providing that acute hemorrhaging is stopped, perforated bowel is repaired, and long-term care provided.

Stress is a condition that is inherent in warfare. Surprise and fear of the unknown contribute significantly to the level of stress that is experienced. The impact of an EBW on an uninformed and unprepared force can lead to psychological casualties that can seriously impact unit cohesion and the will to fight. Providing proper awareness and training to personnel before they encounter this type of threat can minimize psychological disorders. They should remain updated on the threat EBW capabilities and effects. Defensive tactics, techniques/procedures, and medical precautions and treatment should be included in unit standard operating procedure and emphasized in field training exercises. Strong leadership and direction during and after an EBW attack can minimize the psychological effects.

First Aid and Treatment

Although there may be a higher incidence of burns to exposed skin and blast injuries than conventional weapons, the injuries resulting from blast weapons are not radically different from those already witnessed on the battlefield. In urban operations, flying fragments and falling debris will likely lead to an increase in eye, blunt, and crush injuries. These injuries may conceal an underlying blast injury, and medical personnel should be aware of this possibility, particularly in urban operations. Medical planners at all levels should consider the potential for blast injuries when conducting the threat assessment.

Blast injuries can be difficult to diagnose and can take time to reveal themselves, particularly in the case of chest or abdominal blast injuries, which may be accompanied by no external symptoms and therefore may be indistinguishable from combat stress reaction cases (hyperventilation, breathlessness, and agitation). Besides visual indications of injury such as external bleeding, body perforation or skin lacerations, more subtle signs may be evident especially from the primary blast effects. These include deafness, bleeding from the ears, chest or abdominal pain, confusion, disorientation, semi-unconsciousness, eye injuries, difficulty in breathing, or coughing up blood. Early recognition of these symptoms is important for survival.

First aid associated with EBW is essentially the same as any other injury. The primary survey, airway, breathing, and circulation must be addressed first. Traumatic injuries (burns, fractures, and bleeding) are treated in the same way as conventional weapons. A history of exposure to EBW in an otherwise uninjured Soldier should raise the index of suspicion of occult internal injuries. Careful examination by the combat medic, looking for blood from the ears, complaints of chest or abdominal pain, shortness of breath, or cough with bloody sputum, should be undertaken. Appearance of any of these should prompt evacuation to a facility that can intervene appropriately. In treating shock, the use of intravenous (IV) fluids must be based on the clinical parameters of level of consciousness, urine output, and peripheral pulses. Inappropriate use of fluids can cause rapid development of pulmonary problems associated with blast lung (pulmonary contusion). Fluids should not be withheld, but close monitoring of their use is mandatory. Following the current Army guidelines on fluid resuscitation will enable the medic to use fluids more appropriately (See Appendix – Tactical Field Care at the end of this article extract from the 91W Tactical Combat Casualty Care Lesson Plan), these differ from the advanced trauma life support guidelines used in the hospital setting. One exception to the Army guidelines is the use of Hetastarch in the presence of pulmonary contusion. No studies in humans have been done to see if the use of this fluid worsens the clinical picture. Thoughts are that the complex molecule can leak from the damaged vessels and worsen the fluid accumulation in the lungs. Once again, control fluids to stabilize the clinical parameters listed above. Overuse of fluids will rapidly worsen pulmonary contusion and can shorten the onset of clinical signs greatly (onset within 1 or 2 hours versus 24 hours without fluid overload). In real or suspected EBW injuries, the casualty should be put at rest as exercise has been proven to worsen the condition. Therefore, even an ambulatory patient should be moved by litter to minimize further insult.

Evacuate the casualty by the most rapid means possible. Concern has been expressed that the use of aeromedical evacuation platforms may be detrimental to the casualty. With pulmonary contusion and air embolus, rapid and significant changes in altitude can impact survivability. This will be less of a problem with Army rotary wing flying at lower altitude. Packaging the casualty in the appropriate position and all the appropriate tubes in place is equally important. If the equipment is available, the placement of a nasogastric tube, endotrachael tube, IVs, and chest tubes should be considered, based on the patient's condition and underlying pathology. Patients with severe blast injuries will need intensive medical care unavailable in the forward areas of the battle space.

Conclusions

Given current proliferation trends, U.S. forces are likely to encounter EBWs anywhere in the world. The Russian weapons are ruggedly designed and simple to use infantry weapons, making them an excellent and inexpensive force multiplier for conventional, marginally trained, or irregular forces. The EBWs (especially thermobaric and fuel air explosives) provide threat forces with a kill mechanism that circumvents traditional fragmentation protection (body armor and helmets).

Personnel caught directly under the aerosol cloud will die from the flame or overpressure. For those on the periphery of the strike, the injuries can be severe. Burns, broken bones, contusions from flying debris, and blindness may result. Further, the crushing injuries from the overpressure can create air embolism within blood vessels, concussions, multiple internal hemorrhages in the liver and spleen, collapsed lungs, rupture of the eardrums, and displacement of the eyes from their sockets. Displacement and tearing of internal organs can lead to peritonitis. Combat medics are well trained in stopping bleeding, protecting the wound, and treating for shock. Many of the injuries caused by thermobaric weapons are internal and may not be initially detected by the medic. Medical units must incorporate training that includes triage and treating casualties with EBW injuries.

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APPENDIX

Tactical Field Care

1. Airway management
   Chin-lift or jaw-thrust
   Unconscious casualty without airway obstruction: nasopharyngeal airway, Combitube, Laryngeal mask airway.
   Unconscious casualty with airway obstruction: cricothyroidotomy, if other airway techniques are unsuccessful.

Cervical spine immobilization is not necessary for penetrating head or neck trauma.

2. Breathing
   Consider tension pneumothorax and decompress with needle thoracostomy if a casualty has unilateral penetrating chest trauma and progressive respiratory distress.
3. Bleeding
   Control any continued bleeding with a tourniquet or direct pressure.
4. Intravenous
   Start an 18-guage IV or saline lock, consider sternal I/O if unable to start IV.
5. Fluid resuscitation
   Controlled hemorrhage without shock: no fluids necessary.
   Controlled hemorrhage with shock: 6% Hetastarch up to1000mL*.
   No more than 1000 mL of 6% Hetastarch for any casualty.
6. Inspect and dress wounds.
7. Check for additional wounds.
8. Pain control as necessary
   Morphine 5 mg IV wait 10 minutes; repeat as necessary.
9. Splint fractures and recheck pulse.
10. Antibiotics
    Gatifloxacin one tablet every 24 hours for Soldiers who are awake and alert. Cefotetan 2 gm slow-IV push (over 3-5 minutes) for Soldiers who are unconscious. May repeat every 12 hours.
11. Cardiopulmonary resuscitation
    Resuscitation on the battlefield for victims of blast or penetrating trauma, who have no pulse, no respirations, and no signs of life will not be successful and should not be attempted.

*Use of hetastarch solution in blast lung have not been studied, consider LR using mentation, urine output, peripheral pulses as a guide.

Implementing Teledermatology in a Military Clinic

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Introduction

Providing specialized medical care to military beneficiaries in remote areas can be challenging. Away from the extensive resources available at military medical centers, the costs of purchased medical services can be very expensive in many ways. The higher costs are driven by increased charges by specialists, additional ancillary use, patient travel, increased lost duty time, and heavier administrative requirements. Faced with the challenge of providing the necessary specialty care in underserved areas, military medicine has demonstrated a strong interest in telemedicine.[1] Utilizing telemedicine, specialized consults are available to the primary care manager (PCM) without as many of the associated costs.

In the military, dermatology complaints and referrals are common. However, because of the low density of military dermatologists, few military facilities have a trained dermatologist on staff.[2] While the larger volume military hospitals may have this specialty available, smaller military clinics in remote locations do not. Therefore, a PCM in a remote location may assume that reliance on the local civilian network for dermatology may be the most expedient option.

Rodriguez Army Health Clinic (RAHC) located at Fort Buchanan, Puerto Rico, is a satellite clinic of Dwight David Eisenhower Army Medical Center (DDEAMC) located at Fort Gordon, GA. The RAHC is one of many small military clinics located far away from a military medical center. The RAHC provides medical support to elements of the United States Army South, the Fort Buchanan garrison, active guard and reserve personnel, and other eligible beneficiaries in Puerto Rico and the Virgin Islands. There are five PCMs on the RAHC staff who contribute to the provision of primary care to about 5,500 enrolled and line of duty beneficiaries. The RAHC provides laboratory testing, basic radiology exams, and the provision of medications through its pharmacy.

However, most medical conditions beyond the scope of primary care must be referred to the local civilian network. This reliance on the local network leads to several challenges. Most significant of these are higher costs for specialized services and extended waiting times for appointments. The single most common complaint made by RAHC patients who are referred out to the network for care is the extended waiting times. In fact, many patients noted that they waited between 5 and 6 hours for scheduled appointments.

In an effort to reduce some of the beneficiary dissatisfaction, a team from the RAHC, led by a PCM, began looking for ways to reduce referrals to the civilian network. Literature indicated that telemedicine offered significant possibilities. The Association of Telemedicine Service Providers conducted a survey which indicated that dermatology was one of the top three most active clinical specialties in telemedicine consultations.[3] Simultaneously, increased marketing by DDEAMC for its teledermatology program provided the most logical choice. By utilizing teledermatology, the PCM has access to a dermatologist in almost any situation. Teledermatology can assist the PCM with treatment and management of dermatological problems inside the clinic. Taking care of dermatological problems inside the clinic can increase beneficiary satisfaction and decrease some of the associated costs of specialty care. Overall, teledermatology offers significant benefits to both the patient and the PCM.

Teledermatology

Teledermatology primarily operates by two different modalities. The first is called "real-time" telemedicine utilizing video telephone conferencing (VTC), which is an expression of live interactive video between the patient and physician. This modality offers the advantage of direct contact with the specialist. The VTC is more clinically efficient because it allows the patient and the physician to ask questions and exchange more information.[4] Patients favor VTC because they are able to receive an instant diagnosis and treatment for their condition. The VTC modality provides more rapid feedback and educational value to the PCM.[5] To summarize, the ability to directly acquire a clinical history, ask follow-up questions, position the patient and camera for optimal clinical images, and interact directly with the PCM are all advantages of the VTC modality.

There are also disadvantages to the VTC modality. The resolution (detail) and color of most VTC dermatology images are frequently inferior to still photography. The passage of the VTC signal through relays introduces delays in both audio and video presentation. The VTC modality also requires the patient, PCM, telemedicine technician, and the consultant to be available simultaneously for live interaction. This challenge or requirement is frequently underestimated.[6] Finally, the purchase of VTC equipment may prove too expensive for many small health care organizations.

The second modality, store and forward (SF), describes the method of utilizing Internet services, a personal computer, and a digital camera for consultation. The Internet is ideal for SF telemedicine in general, and teledermatology specifically, since it is inexpensive and capable of moving large quantities of information.[7] The SF consultation process is relatively simple. The PCM accesses the specialty Internet site, inputs the clinical information into the web software application, downloads the images of the patient from the digital camera to the PC, and then uploads the images to the software application. The PCM then reviews the completed portion of the consult and submits it for feedback to the dermatologist. Notification of the consult is triggered by an automatic e-mail that is an integrated function of the software. The software and Internet site are protected by a digital certification to ensure security of the patient data on the website. Using the SF modality, a dermatologist reviews the stored information and responds back to the PCM with treatment advice via e-mail. Patient confidentiality is maintained as the reply e-mail only references the secure consult number and lists the dermatologist's advice; it contains no patient information or demographic data of any kind. This system is less expensive to operate, provides enhanced capability to remote locations, and best utilizes the dermatologist's time. It also affords better quality pictures which have been shown to yield higher levels of diagnostic accuracy.[8-10] However, the images are static and more dependent on the operator's expertise in using the equipment. This modality also lacks the interaction between the patient and the provider and provides slower completion of the consult than the VTC mode.[11]

Further studies and improvements in technology will undoubtedly minimize the difficulties and maximize the effectiveness of both of these systems. Utilizing either method, both providers and patients view teledermatology as an effective way of delivering dermatology services in areas where easy access to a dermatologist is unavailable.[12]

Early reports have demonstrated that when compared with traditional hospital consultations, teledermatology is more cost effective in health care costs and in patient's transportation costs and time.[13,14] As for reliability, studies have shown that teledermatology (SF and VTC) diagnosis and treatment outcomes are highly accurate when compared with traditional clinic-based outcomes.[15] In fact, one study reported the accuracy rate as high as 95%.[16] Additionally, and also highly important, when measuring overall patient satisfaction both patients and providers value teledermatology.[17]

Implementing Teledermatology at RAHC

The team reviewed historical referral patterns. On average, the RAHC provided about 200 annual referrals for one-time dermatology appointments with network providers. Concurrently, a review of patient complaint information indicated that extended waiting times at the network dermatology clinics was a significant source of frustration for eligible beneficiaries. After reviewing the clinic operation and available resources, the team chose to implement teledermatology at the RAHC with the SF modality.

Similar to other regional medical centers, DDEAMC (in cooperation with the Southeast Regional Medical Command) provides a teledermatology service. The RAHC team began by identifying the critical mission elements necessary to gain access to this service. These critical elements include: access to the secure Internet site, the purchase of the desired SF equipment, and the arrangement for proper training on the new equipment.

The team arranged for the RAHC PCMs to register at the teledermatology website. Staff members received orientation and training on the new equipment and how to best employ this new technology.

A critical element for implementing teledermatology is the training of the clinic staff personnel. The PCM require training on the software applications, including the steps necessary to create, send, and receive consults. They also require training on proper techniques to effectively employ the digital camera. Finally, most benefit from a review of dermatology terms in order to adequately describe dermatologic lesions or conditions in their e-mail consult to the receiving teledermatologist.

Other staff members, including the nurses and medics, need training also. They play critical roles in the process as consult managers. A consult manager is responsible for entering the patient's clinical history from the PCM's consult form and uploading the digital images into the teledermatology software application on the secure website. They also provide follow-up arrangements as directed by the PCM. Hence, the clinic support staff also require training to successfully launch a teledermatology program.

The team ensured that RAHC set up an area specifically for conducting teledermatology. The program initially saw appropriate patients as they presented. This procedure was quickly abandoned in favor of a more methodical 1 day per week schedule to best utilize the support staff and time required to best employ the technology. The use of a set schedule was useful for the RAHC clinical staff, but also provided a much better system for provision of appropriate follow-up for patients with chronic dermatology conditions.

Results of Teledermatology at RAHC

The implementation of the program began providing immediate benefits for both patients and PCMs. To illustrate this point, a brief case study is presented.

A 37-year-old active duty male came to the clinic complaining of widespread papulosquamous lesions localized on his trunk and chest originating on his hands and forearms with associated pruritis and pain from fissured skin. A PCM examined and evaluated the patient and was unable to provide definitive diagnosis or a treatment plan. The PCM wrote down his objective findings and took multiple digital pictures of the widespread lesions. A consult manager entered the digital pictures and the provider's notes into the software application on the secure teledermatology website. An automatic e-mail notification alerted the attending dermatologist of the consult. Later that day, the consult was reviewed and answered by the attending dermatologist. A possible diagnosis was provided along with a proposed treatment plan. The patient was provided with the treatment the next morning. Treatment and follow-up continued until the condition was resolved.

This case study helps illustrate how teledermatology can significantly enhance the quality and timeliness of care. The patient avoided waiting for the consult to be completed and authorized, the time lost waiting for an appointment to be arranged at a network provider, and the time lost by traveling to the local network for care. The government avoided the costs of purchasing the multiple visits (Puerto Rico is a site which still retains responsibility for paying supplemental care claims).

After 6 months of teledermatology at RAHC, data supports the continued use of the program. During fiscal years 2001 and 2002, the RAHC referred an average of 17 patients per month for dermatology care. For the 6 months following implementation of the teledermatology program at RAHC, referrals for dermatology dropped to 6 per month.

In addition to lowering the referral rate – and the costs – for purchased dermatology care, the teledermatology program has provided an unexpected benefit. The program has provided an avenue for teaching and mentoring the clinic PCMs on dermatologic conditions. The new awareness improves confidence of the PCMs and the delivery of care for dermatology patients. The access to an experienced attending dermatologist has provided additional levels of benefits to PCMs in a remote location.

Conclusion

Teledermatology significantly improved the quality and cost-effectiveness of medical care at RAHC. Before its implementation, RAHC relied on dermatologists from outside the clinic to manage and treat our patients with dermatological concerns. Now, with teledermatology operating at RAHC, the majority of would-be dermatology referrals are being seen and treated within the RAHC. The RAHC's use of teledermatology has significantly decreased the referral rate to dermatologists in the local network by over 67%. Concurrently, the beneficiaries, providers, and staff members have all verbalized satisfaction with the quality of care and administrative processes associated with the utilization of the teledermatology service. Given the extremely low start-up costs and immediate benefit to the beneficiaries, providers, and staff, the implementation and utilization of teledermatology at RAHC is a great success.

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Battlefield Medicine: A Tactical Perspective

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Soldiers continue to die on today's battlefield just as they did during the Civil War. While there have been considerable advances in modern medical care, many of these principles do not apply to care on today's battlefield. Military medical personnel are currently trained to care for combat casualties using the principles taught in the Emergency Medical Technician Basic, Basic Trauma Life Support, and Advanced Trauma Life Support courses (Figure 1). While these courses are appropriate for civilian trauma, they are not appropriate for care in combat. They do not address principles such as enemy fire, medical equipment limitations, a widely variable evacuation time, tactical considerations, and the unique problems in transporting casualties. In the mid-1990s the U.S. Army Special Operations Command conducted a 2-year study to review the issue of battlefield care. Their consensus resulted in the development of a new paradigm on how to care for casualties in combat. This treatment plan breaks up casualty care into three distinct phases: Care under Fire, Tactical Field Care, and Combat Casualty Evacuation Care. In addition, it explores significant differences in providing care on the battlefield than on the streets of anywhere USA. The most important aspect of caring for trauma victims on the battlefield is well thought out planning for that environment and appropriate training of combat medical personnel. Good medicine can sometimes be bad tactics. Bad tactics can get everyone killed and/or cause the mission to fail. "Tactical Combat Casualty Care (TCCC)" has been approved by the American College of Surgeons and the National Association of Emergency Medical Technicians.[1] It has also been included as a new chapter in the Pre-hospital Trauma Life Support Manual 5th edition.[2]

Fig 1. Initial battlefield care.

The pre-hospital phase of care continues to be critically important, since up to 90% of combat deaths occur on the battlefield before the casualty ever reaches a medical treatment facility (MTF). While we have made tremendous strides in battlefield care at echelons II and III, (digital X-ray, surgical care farther forward than ever before), we have done little to change the care available at the point of wounding. The "TCCC" addresses these casualties.

> *"The fate of the wounded lays with those who apply the first dressing"*
>
> COL Nicholas Senn, MD 1844-1908
>
> *"It is difficult to emphasize sufficiently the importance of initial treatment on the battlefield. What the wounded Soldier does on his own behalf, or what his infantry colleagues do for him; and what the company aid man does for a traumatic amputation or gaping wound of the chest, in the thick of battle, in dust and heat or blowing snow − on these simple procedures depend life-and-death…A slight improvement in the skill and judgment of the company aid man will save…more human lives than the attainment of 100% perfection in the surgical hospital".*
>
> COL Douglas Lindsey, MC
> Presentation to the Army Medical Graduate School - 1951

It is known that the three leading causes of preventable death on the battlefield are extremity hemorrhage, tension pneumothorax, and inadequate airway. Our frontline medics need to be trained in principles appropriate for the environment they will find themselves in. They are frequently alone with multiple wounded Soldiers to care for, and the time until evacuation is unknown. Ninety percent of the deaths on the battlefield occur before the casualty reaches a definitive care facility. The killed in action rate can be reduced by 15% - 20% if we incorporate more appropriate care at the point of wounding. With the advent of new guidelines for the use of tourniquets to control hemorrhage, new hemostatic bandages, antibiotics, and analgesia techniques, as well as low volume fluid resuscitation (Figure 2), these techniques will all be incorporated into battlefield care and by doing so, they will save more lives than ever before.

Fig 2. Battlefield resuscitation (IV insertion).

> *"If during the next war you could do only two things, namely (1) put a tourniquet on and (2) relieve a tension pneumothorax, then you can probably avoid between 70 and 90% of all the preventable deaths on the battlefield".*
>
> COL Ron Bellamy

The time has come to integrate the philosophy of "TCCC" into the conventional forces as well. However, the challenge to the Army Medical Department leadership is to implement and train the conventional forces in these principles. Within the next year, many units will rotate into the Middle East where combat continues unabated. Reserve and National Guard units will be deploying into this theatre as well. Now is the time to develop and implement a training program for units who are pending deployment to a combat zone. The combat medic in his delivery of point of wounding care needs to get away from the principles of Advanced Trauma Life Support (ATLS). These principles work well in a hospital emergency room, but do not work on the battlefield. The timely integration of this training with a number of recent innovations in battlefield care will be paramount in saving lives on tomorrow's battlefield. The three goals of TCCC are: (1) treat the casualty; (2) prevent additional casualties; and (3) complete the mission.

Stages of Care

In making the transition from the standards of civilian emergency care to the tactical setting, it is important to consider the management of casualties that occur during combat missions as being divided into three distinct phases: Care Under Fire, Tactical Field Care, and Combat Casualty Evacuation Care. This approach recognizes a particularly important principle – performing the correct intervention at the correct time in the continuum of field care. A medically correct intervention at the wrong time in combat may lead to further casualties.

Care Under Fire is the care rendered by the medic at the scene of the injury while he and the casualty are still under effective hostile fire. Available medical equipment is limited to that carried by the individual Soldier or the medic in his aid bag.

Tactical Field Care is the care rendered by the medic once he and the casualty are no longer under effective hostile fire. It also applies to situations in which an injury has occurred on a mission, but there has been no hostile fire. Available medical equipment is still limited to that carried into the field by medical personnel. Time to evacuation to a MTF, may vary considerably.

Combat Casualty Evacuation Care (CASEVAC) is the care rendered once the casualty has been picked up by an aircraft, vehicle, or boat. Additional medical personnel and equipment that have been pre-staged in these assets should be available at this stage of casualty management.

Care Under Fire

Most medical personnel carry small arms with which to defend themselves in the field. In some unit operations, the additional firepower provided by the medic may be essential in obtaining tactical fire superiority. The risk of injury to other personnel and additional injury to the previously wounded Soldiers will be reduced if immediate attention is directed to the suppression of hostile fire. The medical personnel may, therefore, initially need to assist in returning fire instead of stopping to care for the casualty. The best medicine on any battlefield is fire superiority. As soon as the medic is directed, or is able to, keeping the casualty from sustaining additional injuries is the first major objective. Wounded Soldiers who are unable to participate further in the engagement should lay flat and still if no ground cover is available, or move as quickly as possible if nearby cover is available. If there is no cover and the casualty is unable to move himself to find cover, he should remain motionless on the ground so as not to draw additional fire. There are typically limited medical personnel available. If they sustain injuries, no other medical personnel may be available until the time of evacuation in the CASEVAC phase.

No immediate management of the airway should be anticipated at this time because of the need to move the casualty to cover as quickly as possible. Airway injuries typically play a minimal role in combat casualties. Wound data from previous conflicts indicate airway problems were only 1% - 5% of combat casualties, usually from maxillofacial trauma. It is very important, however, to stop major bleeding as quickly as possible. Injury to an artery or another major vessel may result in the very rapid onset of hypovolemic shock and exsanguination.

The hemorrhage that takes place when a main artery is divided is usually so rapid and so copious that the wounded man dies before help can reach him.

The early treatment of war wounds by COL H.M. Gray, 1919

The importance of this step requires emphasis in light of reports that hemorrhage from extremity wounds was the cause of death in more than 2,500 casualties in Vietnam who had no other injuries.[3] These are preventable deaths. If the casualty needs to be moved, a tourniquet that can be quickly applied by the casualty himself or his battle buddy, is the most reasonable initial choice to stop major bleeding. Although ATLS discourages the use of tourniquets, they are appropriate in this instance because direct pressure is hard to maintain during casualty transport under fire. Ischemic damage is rare if left in place for less than 1 hour, and tourniquets are often left in place for several hours during surgical procedures. In any event, it is better to accept the small risk of ischemic damage to the limb, than to lose a casualty to exsanguination. Both the medic and casualty are in grave danger while a tourniquet is being applied during this phase, and non-life-threatening bleeding should be ignored until the tactical field care phase. The medic rendering care must make the decision regarding the relative risk of further injury, versus that of exsanguination (Figure 3).

Fig 3. Lifesaving tourniquets.

In the case of lower extremity wounds, which give rise to the most severe hemorrhage controlled by tourniquet, it has been my observation, that too few doctors, much less their assistants, have a concept of the constricting pressure required about the thigh to abolish the flow of blood.

Emergency Treatment and Resuscitation at the Battalion Level by MAJ Meredith Mallory 1954

Transport of the casualty will often be the most problematic aspect of providing TCCC. Although the civilian standard of care is to immobilize the spinal column prior to moving a patient with injuries that might have resulted in damage to the spine, this practice needs to be re-evaluated in the combat setting. Arishita et al examined the value of cervical spine immobilization in penetrating neck injuries in Vietnam and found that in only 1.4% of patients with penetrating neck injuries would immobilization of the cervical spine have been of possible benefit.[4] The time required to accomplish cervical spine immobilization was found to be 5.5 minutes, even when using experienced emergency medical technicians. The authors therefore concluded the potential hazards to both patients and provider outweighed the potential benefit of immobilization. However, parachuting injuries, fast-roping injuries, falls greater than 15 feet, and other types of trauma resulting in neck pain or unconsciousness should be treated with spinal immobilization unless the danger of hostile fire constitutes a greater risk in the judgment of the medic.[5]

Standard litters for patient evacuation may not be available for movement of casualties in the care under fire phase. Consideration should be given to alternate methods of evacuation, SKED® or Talon II® litters, dragging the casualty by the web gear, ponchos, even a length of rope with a snap link can be used to drag a casualty out of the field of fire. Additionally, consider the use of obscurants such as smoke or CS (gas tear) to assist in casualty recovery. Vehicles can also be used as a screen during recovery attempts. *There were several instances of tanks being used as screens in Iraq to evacuate casualties.*

There should be no attempt to save a casualty's rucksack unless it contains items that are critical to the mission. His weapons and ammunition should be taken if at all possible; otherwise the enemy may use them against you.

Combat is a frightening experience, and being wounded, especially seriously, can generate tremendous anxiety and fear. Engaging a casualty with reassurance is therapeutically beneficial, and communication is just as important in patient care on the battlefield as it is in the MTF.

Key Points

(1) Return fire as directed or required. (2) The casualty(s) should also continue to return fire if able. (3) Try to keep yourself from getting shot. (4) Try to keep the casualty from sustaining any additional wounds. (5) Airway management is generally best deferred until the Tactical Field Care phase. (6) Stop any life-threatening hemorrhage with a tourniquet. (7) Reassure the casualty.

Tactical Field Care

The Tactical Field Care phase is distinguished from the Care Under Fire phase by more time with which to render care, and a reduced level of hazard from hostile fire. The amount of time available to render care may be quite variable. In some cases, tactical field care will consist of rapid treatment of wounds with the expectation of a re-engagement with hostile forces at any moment. The need to avoid undertaking nonessential diagnostic and therapeutic measures will be critical in such cases. At other times, care may be rendered once the mission has reached an anticipated evacuation point, without pursuit, and is awaiting casualty evacuation. In this circumstance, there may be ample time to render, without haste, whatever care is feasible in the field. The time prior to extraction may range from half an hour or less, to many hours. Care must be taken to partition supplies and equipment in the event of prolonged evacuation times. Although the patient and provider are now in a somewhat less hazardous setting, the Tactical Field Care phase is still not the time or place for some of the procedures taught in ATLS. Procedures such as diagnostic peritoneal lavage and pericardiocentesis obviously have no place in this environment.

If a victim of blast or penetrating injury is found to be without pulse, respiration, or other signs of life, cardiopulmonary resuscitation on the battlefield will not be successful and should not be attempted. Attempts to resuscitate trauma patients in arrest have been found to be futile even in the urban setting where the victim is in close proximity to trauma centers. On the battlefield, the cost of attempting to perform cardiopulmonary resuscitation on casualties with what are inevitably fatal injuries will be measured in additional lost lives, as care is withheld from patients with less severe injuries, and as medics, are exposed to additional hazards from hostile fire because of their attempts.[6] Only in the case of nontraumatic disorders such as hypothermia, near drowning, or electrocution should cardiopulmonary resuscitation be considered prior to the CASEVAC phase. Soldiers with any altered level of consciousness should be disarmed immediately. This simple act may prevent additional friendly casualties.

Initial assessment should be directed to evaluation of airway, breathing, and circulation. There should be no attempt at airway intervention if the patient is conscious and breathing well on his own. If the patient is unconscious, the cause will likely be hemorrhagic shock or penetrating head trauma. The airway should be opened with a chin-lift or jaw-thrust maneuver without worrying about cervical spine immobilization as previously noted. If spontaneous respirations are present and there is no respiratory distress, an adequate airway may be maintained in an unconscious patient in most cases by the insertion of a nasopharyngeal airway.

This device has the advantage of being better tolerated than an oropharyngeal airway should the patient subsequently regain consciousness, and being less likely to be dislodged during patient transport.[7] The patient should also be placed in the recovery position. This position will allow blood and mucus to drain freely.

Should an unconscious patient develop an airway obstruction, the nasopharyngeal airway will need to be replaced with a more definitive airway. Endotracheal intubation is the preferred airway technique in civilian emergency departments, and the ability of experienced paramedical personnel to master this skill has been well documented.[8] However, there are no studies that document the ability of inexperienced medical intubationists to accomplish endotracheal intubation on the battlefield. Another major drawback is the use of white-light from the laryngoscope in a hostile environment. One study that examined first-time intubationists trained with manikin intubations alone noted a success rate of only 42% in the ideal confines of the operating room with paralyzed patients.[9]

Alternatives to endotracheal intubation are the Laryngeal mask airway (LMA) and the Combitube®. These airway devices have been found to provide adequate ventilation without the need for illuminated laryngoscopy. Both the LMA and the Combitube® have been found to be more quickly and reliably inserted by medical personnel with limited experience with endotracheal intubation. The Combitube® has the added advantage of providing better protection of the airway from vomiting and aspiration, and is less easily dislodged with movement of the casualty. Two studies that evaluated the use of the Combitube® by paramedics in prehospital cardiac arrest found it to be effective both as a primary airway and as a backup to endotracheal intubation.[10] Cricothyroidotomy is the other option.[11] This procedure has been reported safe and effective in trauma victims. Although it would typically only be attempted after failed endotracheal intubation, in the hands of a medic who does not intubate on a regular basis, it is probably appropriate to consider this the next step when a nasopharyngeal airway, LMA, or Combitube® is not effective. This technique is also appropriate in the face of maxillofacial injuries in which blood or disrupted anatomy would preclude the use of other airway devices. Oxygen is usually not appropriate for this phase of care because cylinders of compressed gas and the associated equipment for supplying the oxygen to the patient are too heavy to make their use in the field feasible on operations where they must be carried by the medic.

Attention should next be directed towards the patient's breathing. Should the patient be found to have a major traumatic defect of the chest wall, the wound should be covered with petrolatum gauze and a battle dressing. Place the casualty in the sitting position. It is not necessary to vent one side of the dressing since this is difficult to do reliably in a combat setting. An alternative, however, is the "Asherman Chest Seal ®." This chest seal has a one-way valve that would be appropriate for use with penetrating chest trauma. If the casualty develops a tension pneumothorax it should be decompressed as described below. Progressive, severe respiratory distress on the battlefield resulting from unilateral penetrating chest trauma should be considered to represent a tension pneumothorax, and that hemithorax decompressed with a 10-14-gauge catheter. The diagnosis in this setting should not rely on such typical signs as breaths sounds, tracheal shift, and hyperresonance on percussion because these signs may not always be present, and even if they are, they may be difficult to detect on the battlefield.[12] A patient with penetrating chest trauma will generally have some degree of hemo/pneumothorax as a result of his primary wound, and the additional trauma caused by a needle thoracostomy would not be expected to worsen his condition should he not have a tension pneumothorax. The decompression should be carried out with a needle and catheter so that the catheter with the needle removed can be taped in place to prevent recurrence of the tension pneumothorax. This technique must be monitored to ensure the catheter has not clotted or dislodged or that respiratory symptoms have returned. If this is the case, a second needle thoracostomy may need to be performed adjacent to the first. Chest tubes are not recommended during this phase of care, as they are not needed for initial treatment of a tension pneumothorax. They are more technically difficult and time consuming to perform and are more likely to result in additional tissue damage and subsequent infection.

The medic should now address any significant bleeding sites not previously controlled.[5] He should remove only the absolute minimum of clothing to expose and treat injuries, both because of time constraints and the need to protect the patient against the environment. Significant bleeding from an extremity artery or major vessel should be stopped as quickly as possible, using a tourniquet without hesitation as previously described. Otherwise, direct pressure with pressure dressings to control bleeding should be used. New hemostatic dressings (HemCon®) have proven very effective in controlling even arterial hemorrhage. They are applied directly to the bleeding site and held in place for 2 to 4 minutes. Another new hemostatic agent, a powder called QuikClot® is available and has proven to be effective in controlling severe hemorrhage as well. Once the patient has been transported to the site where evacuation is anticipated, consideration should be given to loosening or removing the tourniquet and using direct pressure, hemostatic dressings, or powder to control bleeding if this is feasible and the tactical situation allows.

Intravenous (IV) access should be obtained next. Although ATLS recommends starting two large bore (14-16-gauge) IVs, the use of a single 18-gauge catheter is preferred in the field setting because of the increased ease of starting.

The algorithm for fluid resuscitation in military pre-hospital situations presented below is guided by the critical differences in civilian and military care environments, the need for improved hemorrhage control, the effectiveness of fluid use, and established resuscitation endpoints by the military medic providing care in the forward area.

Assumptions Basic to the New Resuscitation Strategy

- The tactical situation may or may not allow medical care to proceed. Medical care may solely consist of throwing a patient into a ground vehicle or helicopter and evacuating in extremis.

- Lack of hemorrhage control is the leading cause of preventable death on the battlefield. Hemorrhage control is therefore of paramount importance. This may include the use of temporary tourniquets, and in the future, may include injectable methods of hemostasis, and new hemostatic dressings (HemCon®) or hemostatic powder (QuikClot®).[13,14]

- Stethoscopes and blood pressure cuffs, mainstays of civilian pre-hospital care, are rarely available or useful to the front line medic in the typically noisy and chaotic battlefield environment.

- A palpable radial pulse and normal mentation are adequate and tactically relevant resuscitation points to either start or stop fluid resuscitation. Both can be adequately assessed in noisy and chaotic situations without mechanical devices.

- IV access is important for delivery of fluids and medications and thus, early access should be obtained for any casualty with a significant injury. However, only those casualties meeting criteria for resuscitation are given fluids. Casualties with significant injuries should have a single saline lock started with an 18-gauge catheter. One access portal is sufficient and conserves supplies and time.

WW1 Gordon Watson, Consulting Surgeon to the British Second Army – observed that the effects of infused saline were "too often transitory – a flash in the pan – followed by greater collapse than before."

- When IV access is difficult or the tactical situation intrudes, modern intraosseous fluid delivery systems like the First Access for Shock and Trauma (F.A.S.T. 1®), are a reasonable substitute for IV access and a major improvement over "cut downs."[15] Cut-downs are time consuming, technically difficult, and require instruments. They are not appropriate for military pre-hospital use. Medics will not be trained, or equipped, to perform a cut-down.

• Capacity for pre-hospital fluid resuscitation depends on the amount, both weight and volume of fluid that can be carried by each medic and characteristics intrinsic to the fluid itself.[16]

Mission constraints will dictate how much fluid is available on the battlefield:

▪ A medic can be expected to carry up to 6 1000 mL or 12 500 mL bags of fluid.

▪ One 1000 mL bag of lactated Ringers (1100 gm or 2.4 lbs), 1 hour after injection, will expand intravascular fluid volume by approximately 250 mL; one 500 mL bag of 6% Hetastarch (Hextend®) (591 gm or 1.3 lb) expands intravascular fluid volume by approximately 800 mL in a similar time period.[17] One 500 mL bag of Hextend® is functionally equivalent to three 1000 mL bags of lactated Ringers, while there is more than a 5½ pound advantage in the overall weight-to-benefit ratio (1.3 lb to 7.2 lb, respectively). This expansion is sustained for at least 8 hours.

Based Upon These Assumptions, We Have Instituted the following Algorithm of Fluid Resuscitations:

• Superficial wounds (>50% of injured): No immediate IV fluid resuscitation required. However, oral fluid intake should be encouraged.

• Any significant extremity or truncal wound (neck, chest, abdomen, or pelvis) with or without obvious blood loss or hypotension, irrespective of blood pressure:

▪ If the Soldier is coherent and has a palpable radial pulse, blood loss has likely stopped.

▪ Start a saline lock; hold IV fluids; re-evaluate as frequently as situation allows.

• Significant blood loss from any wound and the Soldier has no palpable radial pulse or is not coherent (note: mental status changes due to blood loss only, not head injury):

▪ STOP THE BLEEDING: Direct pressure, hands and gauze rolls, with or without adjuncts like Ace bandages, hemostatic dressings, or hemostatic powder, is primary when possible. Extremity injuries may require temporary use of a tourniquet. However, >90% of hypotensive casualties suffer from truncal injuries unavailable to these resuscitative measures.

▪ After hemorrhage is controlled to the extent possible, obtain IV access and start 500 mL of Hextend®.

- If the casualty's mental status improves and a palpable radial pulse returns, stop IV infusion, maintain saline lock, and observe for changes in vital signs.

- If no response is seen, give an additional 500 mL of Hextend®. If a positive response is obtained, stop IV fluids, maintain saline lock, and monitor vital signs.

▪ Titrating fluids is desirable but may not be possible given the tactical situation. Likewise, the rate of infusion is likely to be difficult to control. Based on the effective volume of Hextend® versus lactated Ringers and coagulation concerns with increasing amounts of Hextend®, no more than 1000 mL of 6% Hetastarch should be given to any one casualty (approximately 10 mL/kg).[18-21] This amount is intravascularly equivalent to 6 liters of Ringers lactate. If the casualty is still unresponsive and without a radial pulse after 1000 mL of Hextend®, consideration should be given to triaging supplies and attention to more salvageable casualties.

• Based on response to fluids, casualties will separate themselves into responders, transient responders, and nonresponders.

▪ Responders are casualties with a sustained response to fluids, probably have had a significant blood loss, but have stopped bleeding. These casualties should be evacuated at a time that is tactically judicious.

▪Transient and non-responders are most likely continuing to bleed. They need evacuation and surgical intervention as soon as tactically feasible. If rapid evacuation is not possible, the medic may need to triage his attention, equipment, and supplies to other casualties as determined by the tactical situation. Remember: no more than 1000 mL of Hextend® should be given to any one casualty.

The fluid resuscitation guidelines promulgated by Henry K. Beecher and the Board for the Study of the Severely Wounded in World War II, based on study of 3,000 combat casualties, is surprisingly similar to the current recommended approach.

Head injuries impose special considerations. Hypotension (SBP<90 mm Hg) and hypoxia (Spo_2<90%) are known to exacerbate secondary brain injury. Both are exceedingly difficult to control in the initial phases of combat casualty care. Given current recommendations on the care of head injury, we cannot at this time recommend hypotensive resuscitation, as outlined above, for the Soldier with obvious head injuries.[22-24] Should the combat situation allow for continuous individual patient attention, the medic can attempt to keep SBP >90 mm Hg via external monitoring of blood pressure and evacuate the casualty to the next higher level of care as soon as possible.

A careful check for additional wounds should be made, since the high-velocity projectiles from modern assault rifles may tumble and take erratic courses when traveling through tissue, often leading to exit sites remote from the entry wound.

For the conscious casualty requiring pain control, if the Soldier is able to continue to fight, consider the use of oral pain meds that will not alter the level of consciousness. Rofecoxib (Vioxx ®) 50 mg orally daily with 1000 mg of Tylenol® every 6 hours will be sufficient to control moderate pain. These medications along with an oral antibiotic make up the individual's "Combat Pill Pack." Soldiers will be instructed to take this pack when they sustain a penetrating wound on the battlefield. This "Combat Pill Pack" (Figure 4), allows for pain medication and antibiotics, two mainstays of combat care, to be accomplished at the same time.

Fig 4. Combat pill bag pain management and infection control for combat casualties.

If the Soldier is unable to fight, he should be given IV morphine for pain control. This mode of administration allows for a much more rapid onset of analgesia and more effective dose titration than an intramuscular (IM) approach. An initial dose of 5 mg of morphine is given and repeated at 10-minute intervals until adequate analgesia is achieved. If a saline lock is used, it should be flushed with 5 mL of normal saline after each dose. Morphine may be administered IM if IV access is not available. The initial dose should be 10 mg and the dosing intervals should be 45 to 60 minutes. Dose and time of morphine administration, should be clearly documented and visible so overdose and respiratory compromise is avoided. Medics administering morphine must also be trained in the use of Naloxone (Narcan®). Soldiers should also not be given any aspirin, ibuprofen, or other nonsteroidal anti-inflammatory drugs while in theatre because of their detrimental effects on hemostasis.

Fractures should be splinted as circumstances allow, ensuring that peripheral pulses, motor, and sensory responses are checked both before and after splinting.

Infection is an important cause of morbidity and mortality in wounds sustained on the battlefield. Gatifloxacin is an oral antibiotic that can be used by casualties who are awake and alert and who have sustained a battlefield injury. One tablet orally every 24 hours is an acceptable dosage regime. Casualties who are unconscious and/or unable to use oral antibiotics can be given IV antibiotics. Cefotetan (2 gm IV) is an accepted monotherapeutic agent for battlefield wounds. Cefotetan is supplied as a dry powder that must be reconstituted with 10 cc of sterile water. It may be given slow IV push over 3-5 minutes, which eliminates the need for piggyback solutions. The saline lock should be flushed as described above. Additional doses should be administered at 12-hour intervals until the patient arrives at a treatment facility. For patients with medication allergies that are felt to contraindicate the use of fluoroquinolones or cephalosporins, other broad-spectrum antibiotics should be selected in the planning phase.

CASEVAC Care

At some point in the operation, the casualties will be scheduled for evacuation. As mentioned previously, the time of extraction may be quite variable, from several minutes to many hours. There are only minor differences when progressing from the Tactical Field Care phase to the CASEVAC phase. The first is that additional medical personnel may accompany the evacuation asset. This may be important for the following reasons: (1) the medic may be among the casualties; (2) the medic may be dehydrated, hypothermic, or otherwise debilitated; (3) the EVAC vehicle's medical equipment will need to be prepared prior to the evacuation; and (4) there may be multiple casualties that exceed the capability of the medic to care for simultaneously.

It may be possible to have more highly trained and experienced medical personnel accompanying the evacuation asset at this point of the operation, and this opportunity should not go to waste.[25] The best arrangement would be a two-person team composed of an aviation medic who is familiar with that particular airframe and a physician or physician assistant with as much recent trauma or critical care experience as possible. Although there may be times when more than two people would be useful, two is probably the most reasonable number because of space constraints within the evacuation asset and a scarcity of specialized medical personnel in theatre.

The second major difference in this phase of care is that additional medical equipment can be brought in with the EVAC asset and would not have to be carried in the tactical ground portion of the operation. Re-supply may also be accomplished at this time as well.

Helicopter transport impairs or precludes the providers' ability to auscultate the lungs or even to palpate the carotid pulse.[26-28] Electronic monitoring systems capable of providing blood pressure, heart rate, pulse oximetry, and capnography are available and may be beneficial for air medical transport care.

Oxygen should be administered to seriously injured patients during this phase of care. Tube thoracostomy is a reasonable option in this phase of care since there should be a provider experienced in this technique present and a more favorable environment in which to perform it.

Patients with controlled hemorrhagic shock may be resuscitated with Hextend® to a mean arterial pressure of 60-80 mm Hg in this phase, since more precise electronic monitoring should now be available. Casualties with penetrating chest wounds or abdominal wounds should still not be aggressively resuscitated, although this decision may be more individualized in the CASEVAC phase by a provider skilled in dealing with trauma patients. An IV rate of 250 mL per hour for patients not in shock will help to reverse mild dehydration and prepare them for possible general anesthesia once they arrive at the MTF. Lactated Ringers solution may be used for fluid resuscitation in these patients because there are no restrictions on weight in this phase and sustained intravascular volume expansion is less critical. Blood products may be a possibility in some cases during this phase.

No attempt should be made during transport to debride or otherwise repair the wounds sustained. The darkness and instability of a rotary-wing aircraft combined with the contaminated and crowded conditions that will usually exist make such efforts unadvisable even when individuals with surgical experience are present.[1]

This approach to the tactical environment and care of combat casualties is better suited to the battlefield than previous civilian-based methods of training and casualty care in years past.

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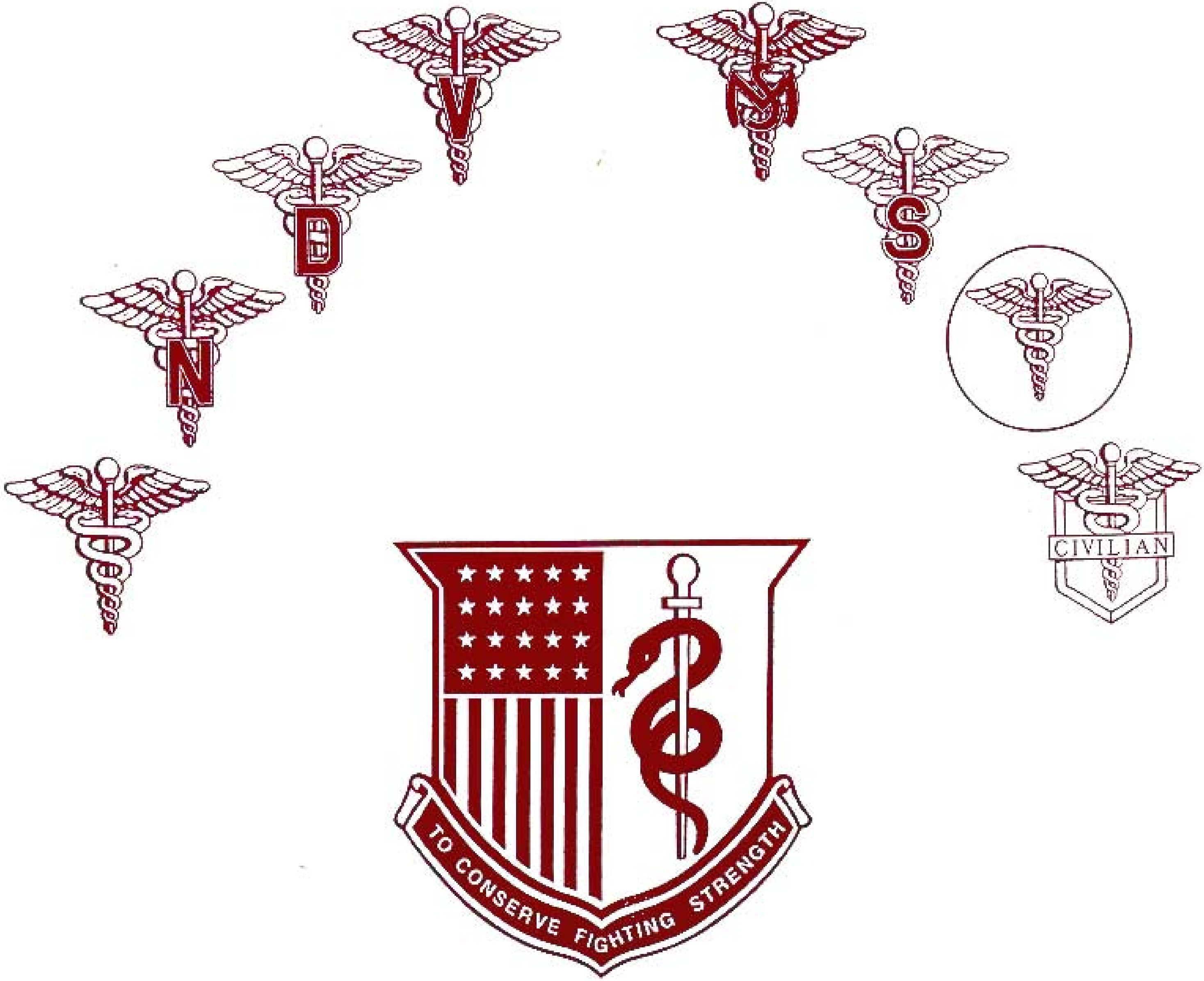
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